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LECTURE NOTES ON PHYSIOLOGY

BY

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THE NERVOUS SYSTEM

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I

THE NERVES

THE PERIPHERAL NERVES

STRUCTURAL BASIS OF THE NERVOUS SYSTEM

The Purpose Served by the Nervous System — The nervous system has developed in order that a rapid communication between the distant portions of the body may be possible. Its tissues in the process of specialization of function have acquired the highest perfection of the vital phenomena of excitability and of the power of transmission of a change dependent on excitement. Among unicellular animals special provision for such a means of communication does not exist. Among the metazoa, *i.e.,* the sponges, no evidence of a nervous system exists. It is in the Cœlenterata that the first evidences of a nervous system are met with.

DEVELOPMENT OF THE NERVOUS SYSTEM

The Hydra — In the hydra some of the epithelial cells have prolongations which join or, at least, come into contact with deeper cells possessing special contractile power. (Fig. 1.) We can imagine that these epithelial cells with their prolongations have become endowed with a special sensitiveness to external irritants, and possess the power of quickly transmitting the effects of the external changes upon it to the contractile cells and in a manner to cause the latter to respond immediately.

Cœlenterates — The jelly fish presents quite an advance over this simple nervous system and no intermediate stages are known. (Fig. 2.) The nervous system of the jelly fish is limited to the region beneath the margin of the umbrella. From the epithelium of the surface, fibers pass inward forming a network around the margins of the umbrella. In this network there are thickenings in which are situated nerve cells. (Fig. 3.) A finer network of

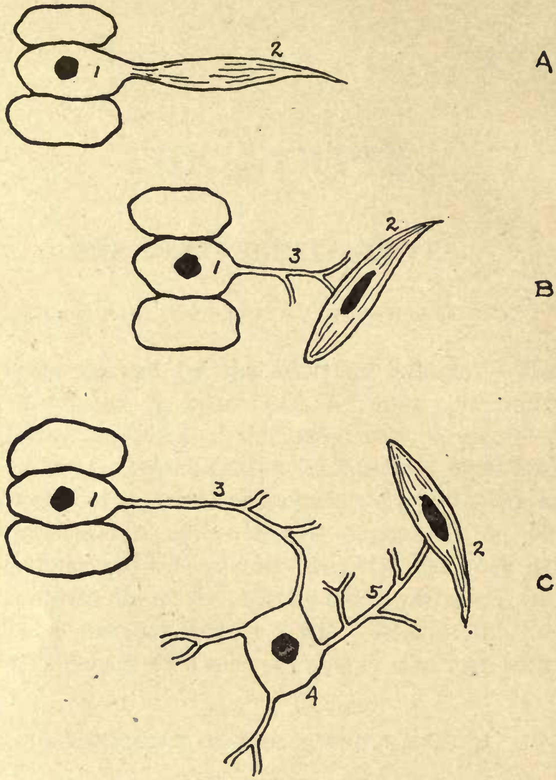


Fig. 1.—Diagrammatic illustration of the evolution of the reflex arc. *A* shows a single cell differentiated into a conductive (1), and contractile portion (2). In *B* the conductive portion (1) and the contractile portion (2) exist as separate cells and maintain their connection with the sensory element by a slender conductive portion in this cell, which represents a nerve (3). In *C* the sensory cell (1) and the contractile element are separate cells, but the connection between the two is maintained by an interpolation of a new nerve cell receiving an afferent extension (3) from the sensory cells and giving off an efferent extension (5) of the muscle cell.

fibers originates in the network just described and terminates around muscular cells (cells, in other words, which have acquired in the process of specialization the highest perfection for that individual animal of the vital phenomenon of contraction). Besides these two sets of nerve fibers, another set of fibers containing small collections of cells also exists beneath the margins of the umbrella.

The various sensitive cells on the surface present differences in their capabilities of responding to various stimuli. Such differences represent specialization of the function of excitability. Some are more sensitive to light, others to the weight of a crystal of lime developed near them, and still others to chemical and contact stim-

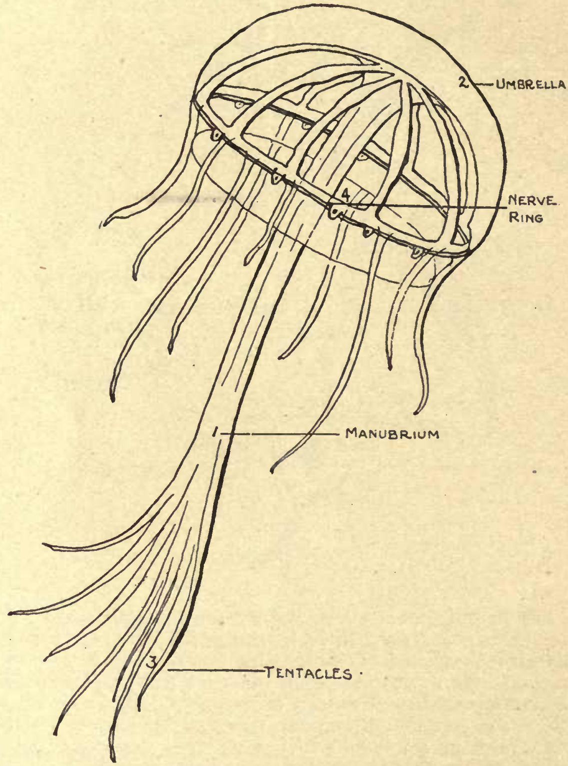


Fig. 2.—Diagram of a jelly fish.
In this organism the central nervous cells are peripherally placed.

uli. By cutting off the marginal ring with its marginal bodies we will remove the special sense organs and the ganglion cells of the umbrella. Such a mutilated jelly fish lies perfectly motionless in the water. It is incapable of any automatic activity because deprived of cells sensitive to external changes its muscle cells receive no stimuli. If a stimulus is applied to the cut nerves running to

the contractile cells within, the jelly fish will contract. Under these conditions the manubrium will bend in the direction of the stimulus.

A more Advanced Stage with Centrally placed Ganglion Cells — In the jelly fish the ganglion cells, which we may term perhaps switch stations or relay stations, are situated around the periphery of the body. It will be a manifest advantage to an animal to have these switch stations situated centrally. Animals with centrally situated stations, such as the worms, represent the next stage in the development of a nervous system. (Fig. 4.)

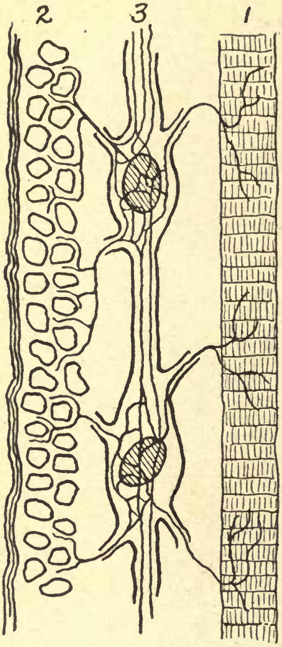


Fig. 3.—Illustrating the communications between the muscle (1) on one side of the umbrella and the sensory epithelium (2) upon the other side through the peripherally placed cells (3).

The Crayfish — A still further advance is represented in animals such as the crayfish, in which the head ganglia, those in the direction in which the animal moves forward, show a special development.

In these animals we have the rudiments of projicient sense organs, organs furnishing the animal with information of what is in the course of its advance. They may be not improperly termed organs of foresight. Through the connecting strands of fibers between these anterior organs and the ganglia behind them impulses may be sent to check forward movement when danger ahead is scented. These impulses are the beginnings of inhibitory impulses. In all these primitive forms of nervous systems, as in the jelly fish, the nervous system starts its development from the surface epithelial cells.

The Sensory Cell — The differentiated peripheral sensory cell possesses two processes — a short one passing to the surface, and a long one passing back to intermingle with a network of fibers in the interior of the animal. (Fig. 5.)

The Central Ganglion — This network also contains ganglion

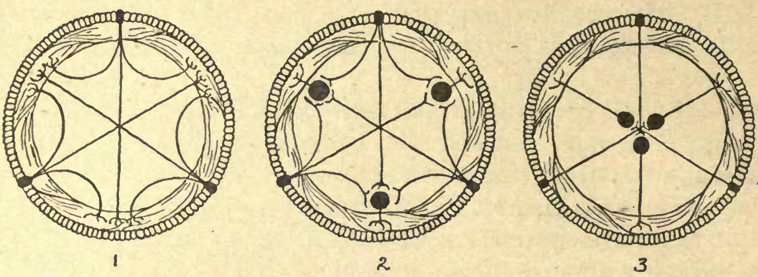


Fig. 4.—Illustrating the stages in the evolution of a centrally placed nerve cell.
In 1 direct communication between the muscle and sensory cell.
In 2 indirect communication between the sensory cell and the muscle through a peripherally placed nerve cell.
In 3 indirect communication between the sensory cell and the muscle through a centrally placed nerve cell.

cells, the processes of which also intermingle with terminal divisions of the processes of the differentiated surface epithelial cells. The intermingling of the fibers forms a network embedded in a granular substance more or less encapsulated and forming a ganglion. While many of the fibers of the ganglion cells participate in the

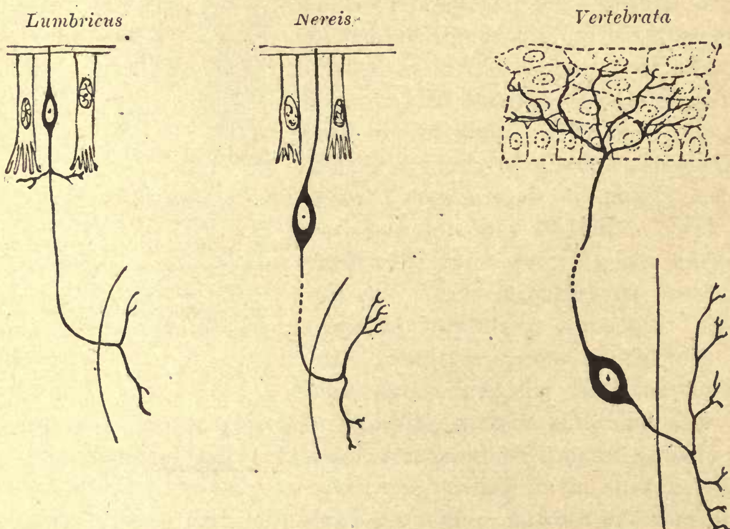


Fig. 5.—Diagrams showing the relative position of the sensory cell in lumbricus, nereis, and vertebrata. (Quain.)

formation of the network, one long process from some of the ganglion cells passes to a muscle cell of the animal. It is believed that some divisions of the long fibers from the differentiated sensitive epithelial cell may become a part of the central ganglion cell and pass directly through it. If this occurs it is exceptional, but it is significant that some fibers of the terminal network from the differentiated sensitive epithelial cell may pass directly into a fiber running to a muscle without at any time becoming a part of a central

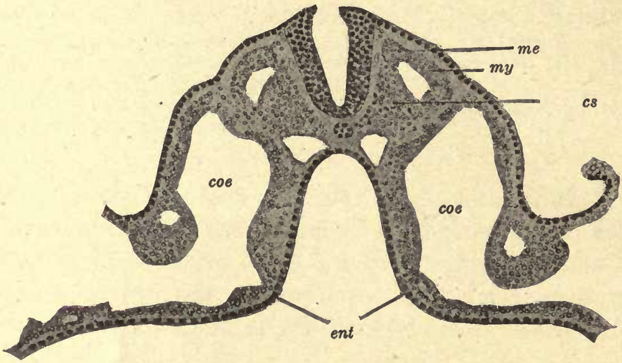


Fig. 6.—Transverse section of a human embryo of 24 mm. (Quain.) *ent*, entoderm of yolk-sac; the lines indicate the points of the splanchnopleuric layers which will come together to cut off the gut from the cavity of the yolk-sac; *my*, outer wall of mesodermic segment; *mc*, the part of its wall which forms the muscle-plate; *sc*, sclerotome; *coe*, cœlom.

nerve cell. This primitive system is thus composed of two elements — the receiving element, which is the differentiated sensitive epithelial cell with its short and long process, and the reactive element, or the peripherally running nerve to the muscle, which may or may not arise in a central nerve cell. The one is called the sensory or afferent neuron and the other the motor or efferent neuron.

The Embryological Development of the Nervous System of the Vertebrates — The nervous system of vertebrates is developed from the epithelium of a groove which forms upon the dorsum of the embryo. This groove subsequently becomes transformed into a canal. At the front end three cavities become formed from which the three brains develop. From the greater length of the canal posteriorly the spinal cord forms. (Figs. 6–9.)

The Spongioblasts and Neuroblasts — The canal is formed of

columnar cells between the outer ends of which small rounded cells are found. From the columnar cells, called spongioblasts, is formed the neuroglia by the production of branching processes. Many of the columnar cells wander externally and become transformed into round cells with many branches. These branches form the supporting network of the nervous system, the neuroglia. (Figs. 10–

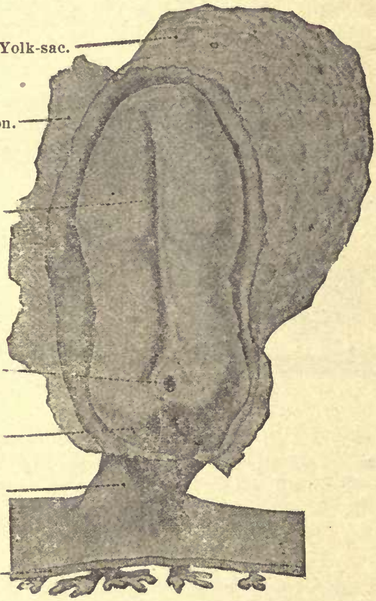


Fig. 7.—Surface view of early human embryo, 2 mm. in length (after Graf. v. Spec.) x 30 diameters. (Quain.)

The amnion is opened, and on the blastoderm are seen the primitive streak, the dorsal opening of the neurenteric canal, and the neural groove.

13.) The round cells appearing in the intervals between the outer ends of the columnar cells are termed neuroblasts.

The Development of the Sensory and Motor Nerve Fibers— From the neuroblasts grow out a process which at first has a bulb-shaped extremity. (Fig. 15.) By continued growth of the process finally reaches the periphery, to end in a muscle or gland. (Figs. 14, 15.) This process is called the axis cylinder of the nerve cell. After the growth of the axis cylinder is well advanced other processes grow out from the cell and terminate ultimately in a series of

branches called dendrites. These cells constitute the efferent path of the central nervous system. The afferent path develops from cells formed outside the primitive neural groove from cells which

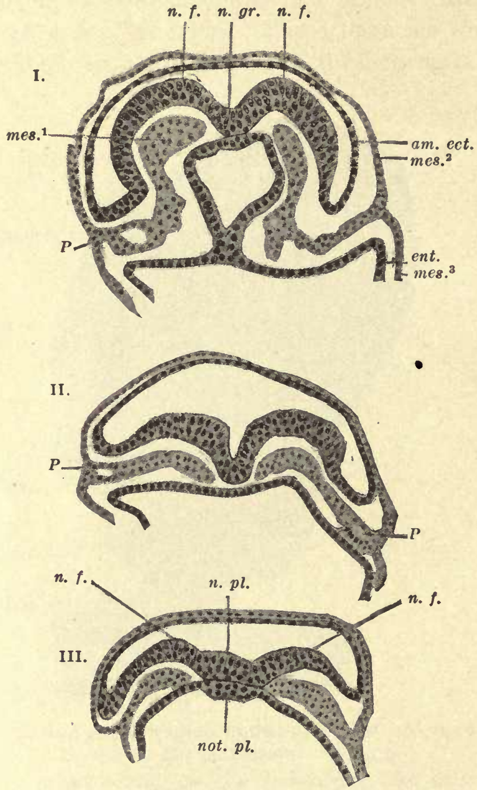


Fig. 8.—Transverse sections of the human embryo of 2 mm. represented in Fig. 7. (Quain.)

In I, which is most anterior, the fore-gut is separated off from the yolk-sac. *n. gr.*, neural groove; *n. f.*, neural folds; *n. pl.* (in III), neural plate; *mes.*[1], intra-embryonic mesoderm; *p.*, pericardial cœlom; *am. ect.*, amniotic ectoderm; *mes.*[2], amniotic mesoderm; *ent.*, entoderm of yolk-sac; *mes.*[3], mesoderm of yolk-sac; *not. pl.* (in III), notochord-plate.

form a longitudinal thickening just external to the latter. From these cells two processes grow out, one from each pole. (Figs. 17–20.) The peripheral one grows to the surface to terminate in a sentient epithelial cell. The central one grows internally into the

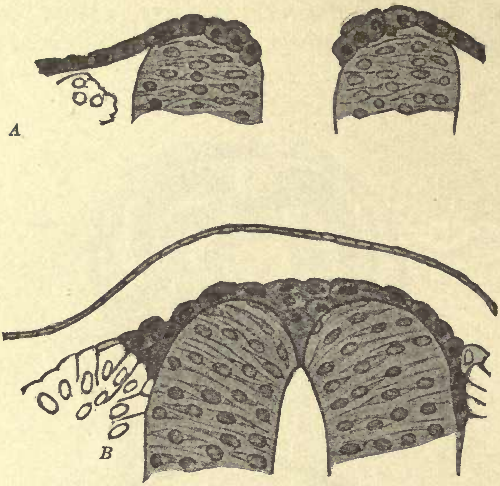


Fig. 9.—Closure of neural canal of human embryo, showing the cells of the neural crest becoming separated to form the germs of the spinal ganglia. (Quain.)

A, canal still open; *B,* canal closed.

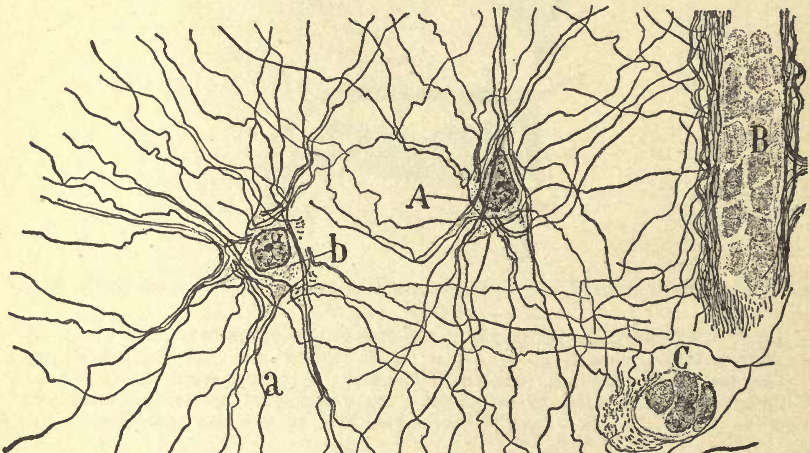


Fig. 10.—Neuroglia cells and fibres from the white matter of the human cerebellum stained by Weigert's neuroglia stain. *A,* Neuroglia cell; *B,* blood-vessel cut longitudinally, and *C,* blood-vessel cut transversely, showing enveloping neuroglia fibres; *a,* neuroglia fibres; *b,* cytoplasm of neuroglia cell. (Bailey.)

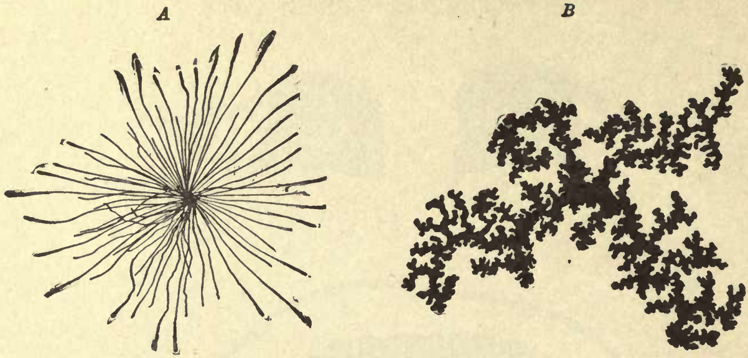


Fig. 11.—*A,* Neuroglia cell—spider type—human cerebrum. *B,* Neuroglia cell—mossy type—human cerebrum. (Bailey.)

Fig. 12.—Neuroglia-cells of cerebellum. Golgi method. (Quain.) *a,* spider-cells; *b,* arborescent cells; *c,* ependyma-like cells.

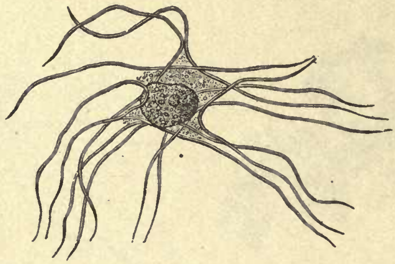


Fig. 13.—A neuroglia-cell, isolated in 33 per cent. alcohol. (Quain.)

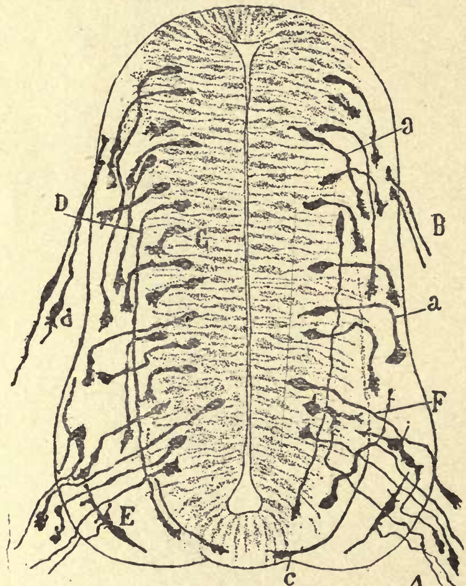


Fig. 14.—*A,* ventral root-fibres; *B,* dorsal root-fibres; *C,* a neuroblast beginning to bud out; *D,* a neuroblast with long fibre passing towards ventral commissure; *E,* a motor neuroblast with axon and dendrons; *F,* a motor neuroblast with axon only: the axon is expanded at the growing end; *a, a,* neuroblasts with axons growing into the lateral column; *c,* growing end of axon of a commissural fibre; d, a cell of the spinal ganglion. (Quain.)

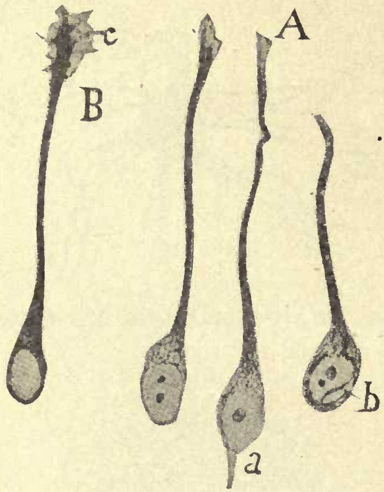


Fig. 15.—Neuroblasts from the spinal cord of a third-day chick-embryo. (Quain.)

A, three neuroblasts, stained by Cajal's reduced-silver method, showing a network of neurofibrils in the cell-body; *a*, a bipolar cell. *B*, a neuroblast stained by the method of Golgi showing the incremental cone (*c*).

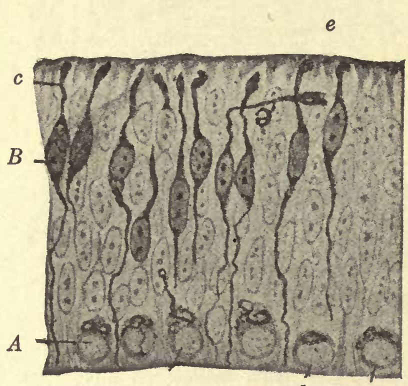


Fig. 16.—Section of wall of neural tube (first cerebral vesicle) of chick of three and a half days. (Quain.)

A, germinal layer containing rounded neuroblasts, *a*, *b*, *c* (these already possess fibrils); *B*, bipolar neuroblasts; *c*, enlarged growing end of axon; *e*, an axon growing tangentially.

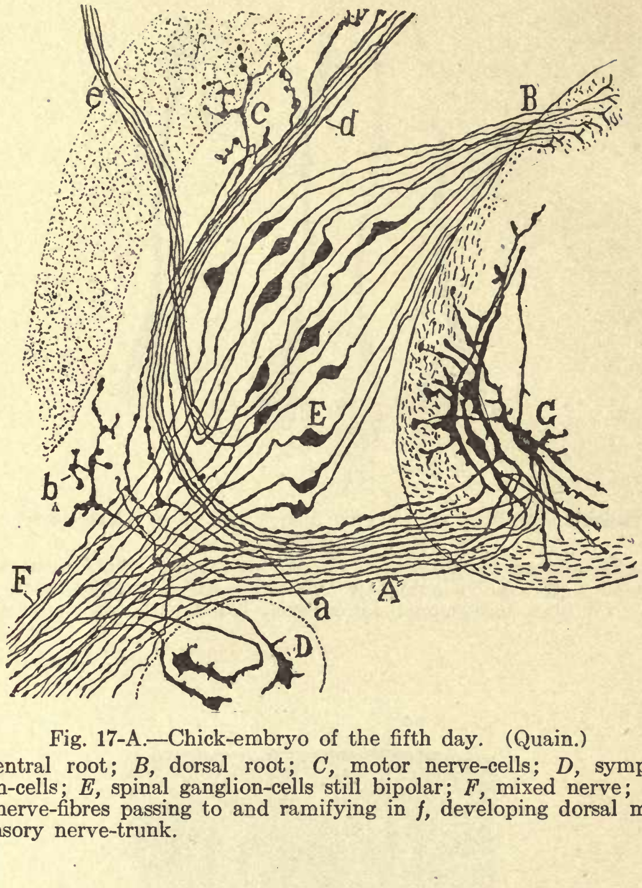


Fig. 17-A.—Chick-embryo of the fifth day. (Quain.)

A, ventral root; *B,* dorsal root; *C,* motor nerve-cells; *D,* sympathetic ganglion-cells; *E,* spinal ganglion-cells still bipolar; *F,* mixed nerve; *b, c, d,* motor nerve-fibres passing to and ramifying in *f,* developing dorsal muscles; *e,* a sensory nerve-trunk.

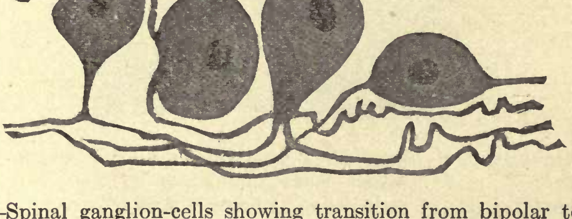


Fig. 17-B.—Spinal ganglion-cells showing transition from bipolar to unipolar condition. (Quain.)

spinal cord to terminate in the neighborhood of some central cell developed from the original neural groove. The two processes of the afferent cell at their origin from the cell ultimately approach

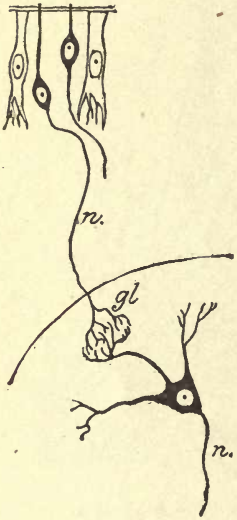


Fig. 18.—Diagram of the arrangement of the sensory nerve-fibres in the olfactory organ and bulb. (Quain.)

n, nerve-fibre coming off from sensory nerve cell; *gl.,* synapse within olfactory glomerulus; *n,* nerve-cell and nerve of olfactory bulb of brain.

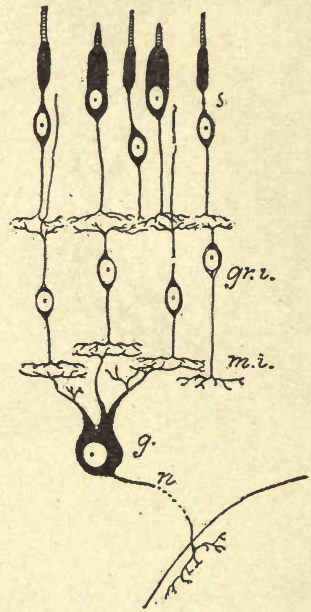


Fig. 19.—Diagram of the connections of the retinal elements. (Quain.)

s, sensory nerve-cells; *gr. i,* inner granules; *m. i.,* inner molecular layer; *g.,* ganglion-cell; *n,* its nerve-fibre process ramifying in the nerve-centre.

each other so that they finally form a T and appear to be given off from a common stem. Because of the double process originally possessed by these cells they are called in the early period of their development bipolar cells. (Figs. 17, A and B.) In mammals all ultimately become unipolar except the cells of the spiral and vestibular ganglia, from which the fibers of the eighth cranial nerve grow. These retain the primitive bipolar arrangement.

The Development of the Medullary Sheath — Some time after the outgrowth of the axis cylinder the medullary sheath is formed, apparently through the agency of the axon itself. The philogenet-

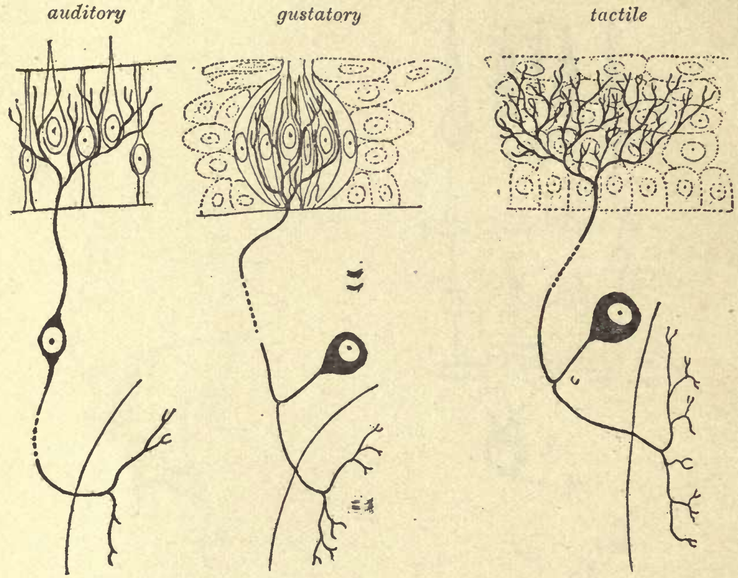


Fig. 20.—Diagram showing the mode of termination of sensory nerve-fibres in the auditory, gustatory, and tactile structures of Vertebrata. (Quain.)

ically youngest fibers in the body acquire a medullary sheath later than others. Representatives of this class are the fibers of the pyramidal tracts and the long posterior columns of the spinal cord.

THE MORPHOLOGY OF NERVOUS TISSUE

The Structure of a Nerve Cell (Figs. 21–30) — A nerve cell possesses, like all cells, a nucleus. The nucleus, though of large size, contains very little chromatin, generally collected as two small nucleoli within the nucleus. Throughout the nerve cell run many fibrillæ which appear in well prepared specimens as delicate striations. These fibrillæ are continued out of the cell into the processes of the cells between the Nissl substance. The Nissl substance is very abundant except at that region from which the axis cylinder leaves the cell. In this region many fibrillæ are collected together to enter the axis cylinder. It is called the axon hillock of the cell. The cell processes are of two kinds and have already been indicated.

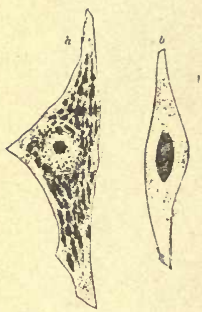


Fig. 21.—Two motor nerve-cells from the dog. (Quain.)

a, normal; *b*, after a period of prolonged activity. (Photographed from preparations by Dr. Gustav Mann.)

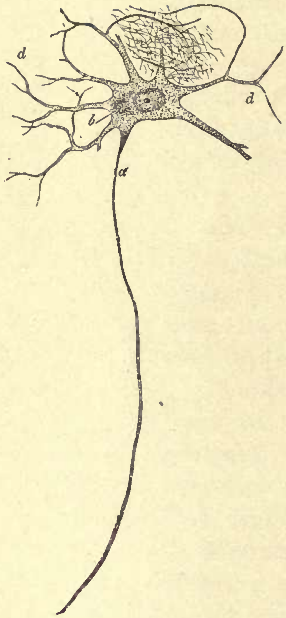
The Axis Cylinder and Dendrites — The axis cylinder is smaller than the other processes, where it leaves the cell, but much longer, running, in the case of motor cells of the spinal cord, to the periphery of the body.

The dendrites are usually thick where they leave the cell but soon break up into many processes which form a network with similar processes of other cells not far from the cell from which they originate.

Neurons — A nerve cell with its processes is termed a *neuron*. The function of neurons is to transmit nervous impulses and, corresponding to the direction of the impulse, there are two varieties of neurons — the sensory or afferent neurons, and the motor or efferent neurons.

An afferent neuron functionally connected through the central nervous system with an efferent neuron constitutes a reflex arc. Though an impulse may be transmitted in either direction along a nerve fiber it can only traverse a reflex arc in one direction. This phenomenon is termed the law of forward direction.

The Structure of Nerves (Figs. 31–32) — All the nerves which are given off from the central nervous system, the brain and spinal cord, possess a medullary sheath. This consists of a fatty substance termed myelin, imbedded between the meshes of a network. The



A

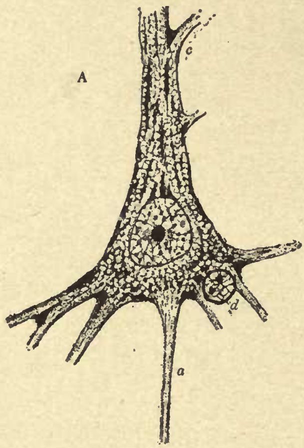
Fig. 22-A.—Ramified nerve-cell from ventral horn of spinal cord of man. (Quain.)

a, axis-cylinder process; *b,* cell-body with nucleus and clump of pigment-granules; *d, d,* dendrons.

B

Fig. 22-B.—Axis-cylinder process of a nerve cell. (Quain.)

x, x, portion of nerve-cell from spinal cord of ox, with axis-cylinder process, *a,* coming off from it and acquiring at *a*[1] a medullary sheath, highly magnified.



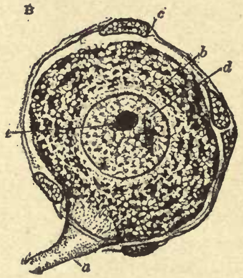


Fig. 23.—Multipolar and unipolar types of nerve-cell. (Quain.)

A, large pyramidal cell of cerebral cortex, human, Nissl method. (Cajal.) *a*, axon; *b*, cell-body; *c*, apical dendron; *d*, placed between two of the basal dendrons, points to the nucleus of a neuroglia-cell.

B, unipolar cell from spinal ganglion of rabbit, Nissl method. (Cajal.) *a*, axon; *b*, circumnuclear zone, poor in granules; *c*, capsule; *d*, network within nucleus; *e*, nucleolus.

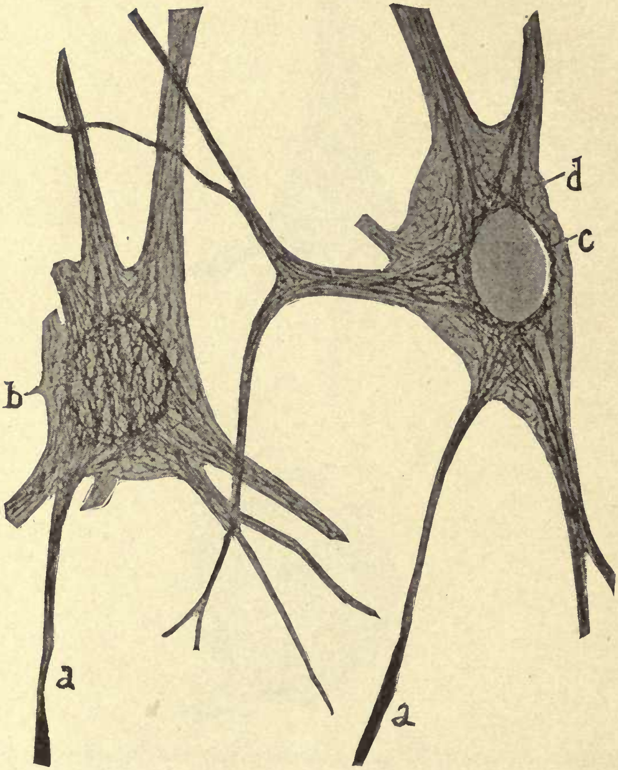


Fig. 24.—Nerve-cells of kitten (from the anterior corpora quadrigemina) showing neuro-fibrils.
a, axon; *b, c, d,* various parts of the intracellular plexus of fibrils.

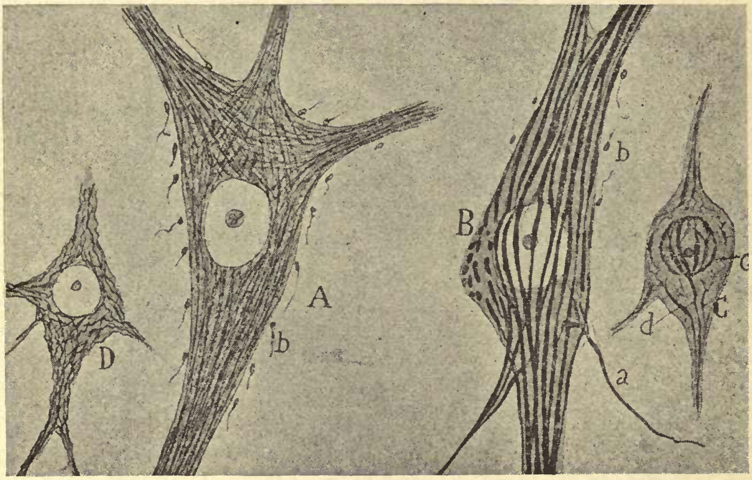


Fig. 25.—Nerve-cells of lizard: *A* and *D* during activity, *B* and *C* during hibernation. (Quain.)

a (in *B*), axon; *b*, *b* (in *A* and *B*), knob-like endings of extraneous fibrils; *c*, *d* (in *C*), superficial and deep fibril networks.

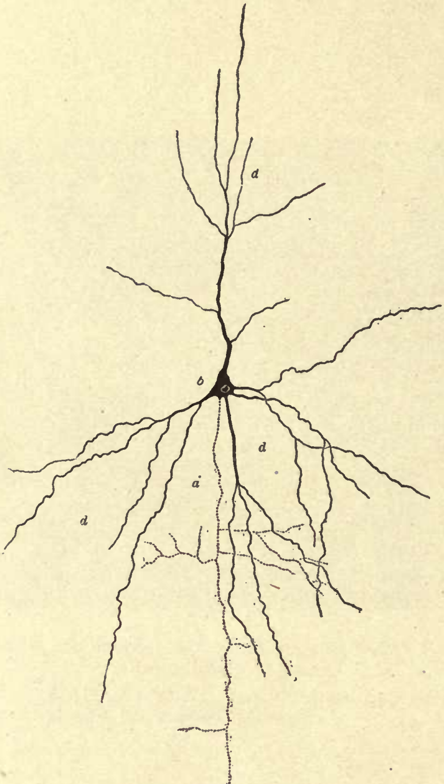


Fig. 26.—A long-axoned nerve-cell from the cerebral cortex. (Quain.) *a,* axis-cylinder process with collaterals; *d, d,* dendrons; *b,* body of cell.

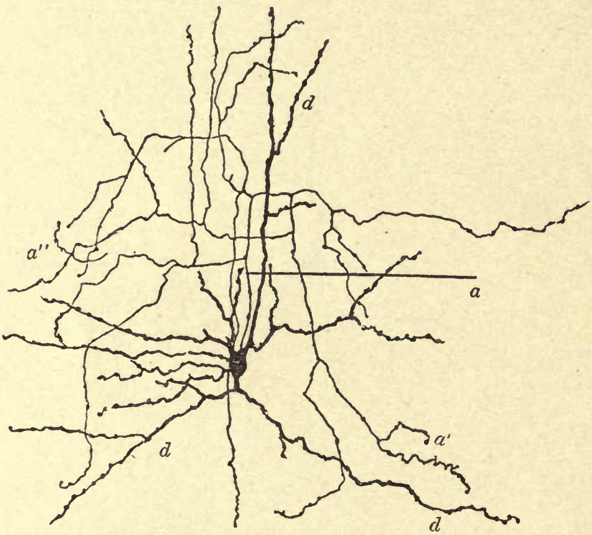


Fig. 27.—A short-axoned cell from the cerebral cortex. Golgi method. (Quain.) *a, a′, a″*, axon and its ramification; *d, d, d*, dendrons.

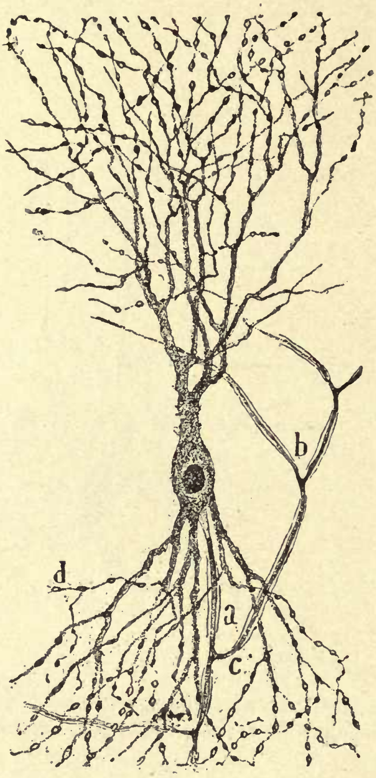


Fig. 28.—Cell from cerebral cortex, showing varicosities on its dendrons and not spines. Methylene-blue method. (Quain.)

a, axon; *b, c,* a branching collateral (both this and the main axon show a medullary sheath); *d,* varicose dendrons.

Fig. 29.—Synaptic ramifications of axon of one nerve-cell, *B*, around the bodies of other cells, *A*. From the cerebellum of the rat. (Quain.) *a, b, c,* ramifying axon; *d,* dendrons.

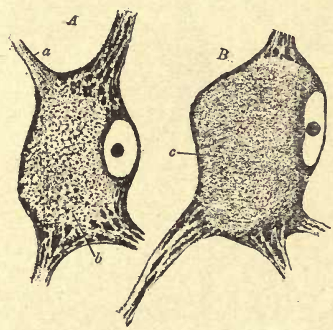


Fig. 30.—Two motor cells from the rabbit's spinal cord, which show chromatolysis as the result of section (fifteen days previously) of the nerve-fibres which arise from them. (Quain.)

In *A* the chromatolysis is rather less advanced than in *B*. In both the nucleus has moved to the periphery, and the cell-substance (*b* and *c*) is swollen. *a,* axon-process of *A*.

Fig. 31.—Transverse and longitudinal section of medullated nerve-fibre of frog (osmic acid and acid fuchsine). (Quain.)

The longitudinal section shows one node of Ranvier and two of Lantermann's clefts. The fibrillar structure of the axis-cylinder is shown in both longitudinal and transverse section.

network is composed of a substance termed neurokeratin. Outside the myelin substance is a sheath termed the neurolemma. Inside the myelin and separating it from the axis cylinder is the axolemma. The axis cylinder itself is composed of many fine fibrillæ, the so-called neurofibrillæ. At certain intervals along the nerve fiber, intervals proportionate to the diameter of the nerve fiber and varying from 80 to 600 microns, the myelin substance suffers interruption so that the medullary sheath dips down to touch the axis cylinder. These interruptions are called the *nodes of Ranvier.* The nerve fibers of the peripheral nerves run in bundles, surrounded and held together by a connective tissue sheath termed the perineurium.

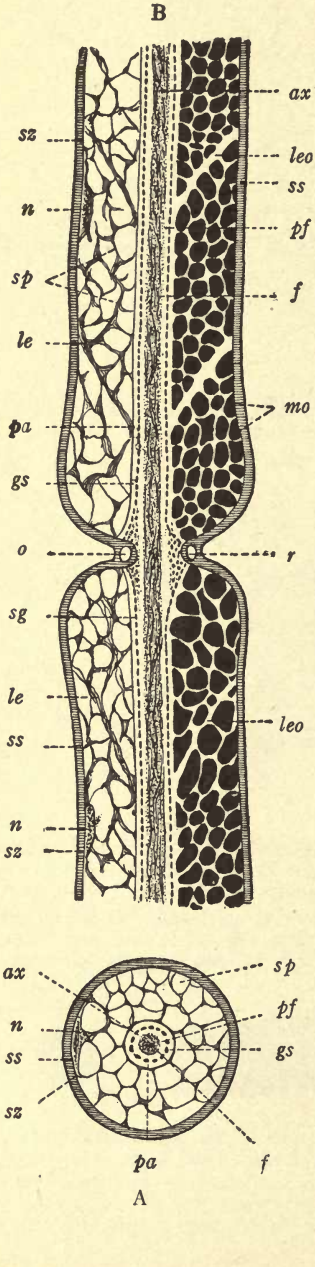


Fig. 32.—Scheme of structure of medullated peripheral nerve fibre of a fish. (Nemileff.)

A, Cross section; *B,* longitudinal section; on left fibre is shown as stained *intra vitam* with methylene blue; on right, myelin is shown black as in osmic acid staining with the incisures of Schmidt indicated; *sz,* cells of sheath of Schwann; *n,* their nuclei; *ss,* sheath of Schwann; *sp,* processes of the cells of sheath of Schwann or the myelin sheath network; *le,* larger trabeculæ of protoplasmic framework of medullary sheath arranged obliquely to axis-cylinder and forming the so-called "funnels"; *leo,* clear streaks in fibres treated with osmic acid, corresponding to *le,* incisures of Schmidt; *mo,* myelin blackened with osmic acid; *ax* axis-cylinder; *pa,* periaxial space around axis-cylinder; *gs,* "coagulated fluid" in periaxial space; *pf,* peripheral, non-fibrillar, part of axis-cylinder; *f,* neurofibrils of axis-cylinder; *r,* ring-like thickening of Schwann's sheath at node of Ranvier; *o,* cavity in *r.* (Bailey.)

The Varieties of Peripheral Endings of Sensory Nerves — The peripheral process of the afferent nerve cell forms a connection with the peripheral epithelium in a variety of ways.

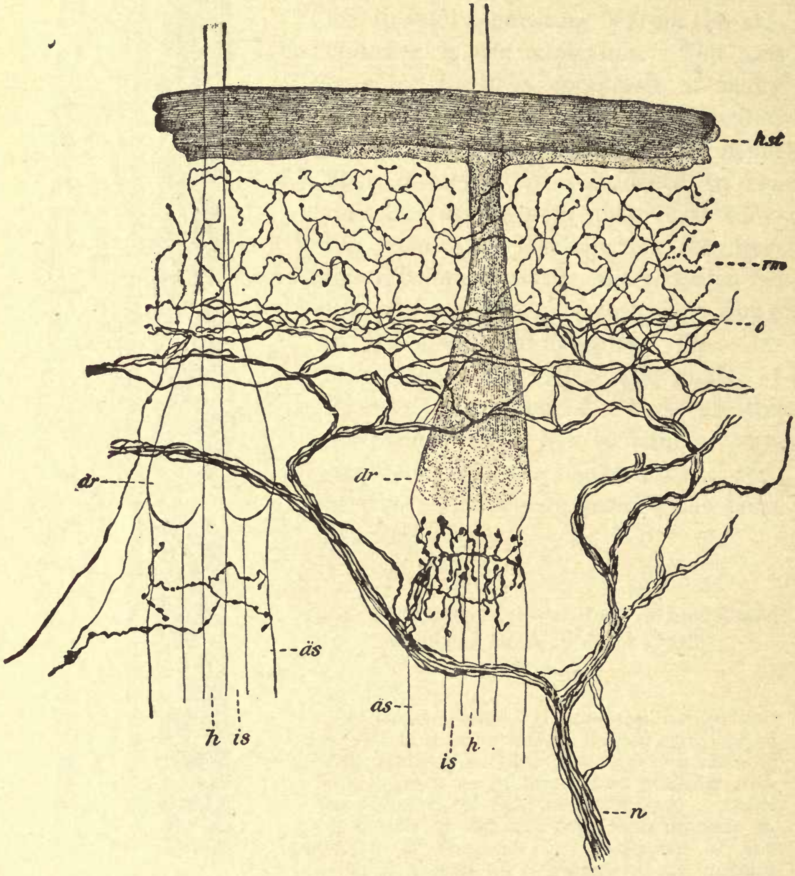


Fig. 33.—Nerve and nerve endings in the skin and hair follicles. (After G. Retzius.)

As, Outer root sheath; *c,* most superficial nerve-fibre plexus in the cutis; *dr,* sebaceous glands; *h,* the hair itself; *hst,* stratum corneum; *is,* inner root sheath of hair; *n,* cutaneous nerve; *rm,* stratum germinativum Malpighii. (Bailey.)

1. In some instances it merely terminates by ramifying between epithelial cells. Losing its medullary sheath it divides a number

of times. Each division ending in a little knob between epithelial cells. (Fig. 33.) Nerve fibers end in this manner which run:

(1) To the skin.

(2) To the mucous membranes.

(3) To connective tissue.

(4) To the glandular epithelium.

(5) To certain serous surfaces.

(6) To the outer sheath of the root of a hair follicle.

(7) To the teeth. Whether the dentine is penetrated by nerve fibers is a matter of dispute.

2. In certain regions of the body where special sensitiveness is required these endings are formed by a combination of complicated variations of the sensory epithelium with the nerve ending. The simplest of these special end organs is the *tactile cell.* It consists of an epithelial cell with a prolonged inner extremity which comes into contact with a leaf-like expansion of the end of the nerve fiber.

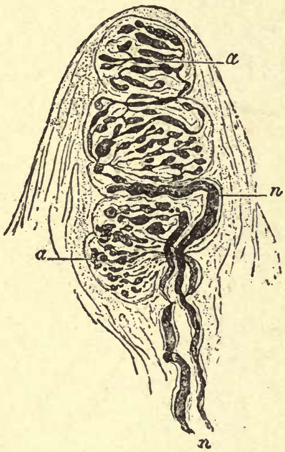


Fig. 34.—Tactile corpuscle within a papilla of the skin of the hand, stained with chloride of gold. (Quain.)

n, two nerve-fibres passing to the corpuscle; *a, a,* varicose ramifications of the axis-cylinders within the corpuscle.

3. A more complex ending is the *compound tactile cell.* This consists of several epithelial cells grouped together and in contact with one nerve ending. Representatives of this class are the *corpuscles of Grandry* and *Merkel's corpuscles.* (Figs. 34 and 36.)

4. *End bulb.* In this form the bulbous end of the axons terminate in a special granular matter inclosed in a capsule of flattened connective tissue like cells. They occur in the mouth and conjunctiva. (Fig. 35.)

5. Compound end bulbs are combinations of several simple end bulbs containing several nerve endings. They occur in the nose, rectum, peritoneum tendon, ligaments, joints and in the trunks of nerves upon the glans penis and clitoris. (Fig. 37.)

6. *Pacinian bodies.* In this form the axis cylinder terminates in a rod which is inclosed in alternate concentric layers of a modified

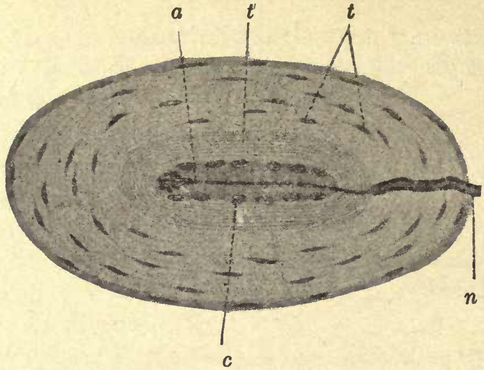


Fig. 35.—Herbst corpuscle of duck. (Quain.) x 380 diameters.

n, medullated nerve-fibres; *a,* its axis-cylinder, terminating in an enlargement at end of core; *c,* nuclei of cells of core; *t,* nuclei of cells of outer tunics; *t',* inner tunics.

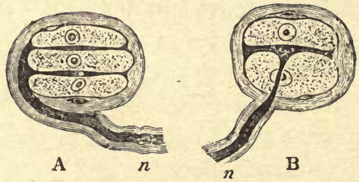


Fig. 36.—Corpuscles of Grandry from the duck's tongue. (Quain.)

A, composed of three cells, with two interposed discs, into which the axis-cylinder of the nerve, *n,* is observed to pass; in *B* there is but one tactile disc enclosed between two tactile cells.

Fig. 37.—A medullated fibre terminating in several end-bulbs in the human peritoneum. Lower power. Methylene-blue preparation. (Quain.)

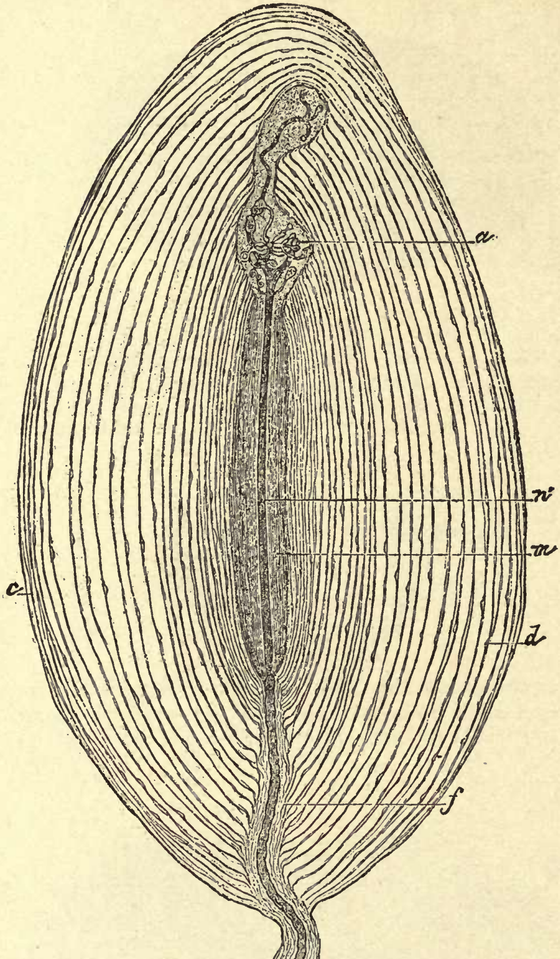


Fig. 38.—Magnified view of a Pacinian body from the cat's mesentery. (Quain.)

n, stalk of corpuscle with nerve-fibres, enclosed in sheath of Henle, passing to the corpuscle *n'*, its continuation through the core, *m,* as axis-cylinder only; *a,* its terminal arborization; *c, d,* sections of epithelioid cells of tunics, often mistaken for the tunics themselves; *f,* channel through the tunics which expands into the core of the corpuscle.

Fig. 39.—Nerve-endings upon the intrafusal muscle-fibres of a muscle-spindle of the rabbit. Moderately magnified. Methylene-blue preparation. (Quain.)

a, large medullated fibre coming off from "spindle" nerve and passing to end in an annulo-spiral termination on and between the intrafusal fibres; *b,* fine medullated fibres coming off from the same stem and dividing. Its branches, *c,* pass towards the ends of the muscle-fibres and terminate in a number of small localized arborizations, like end-plates.

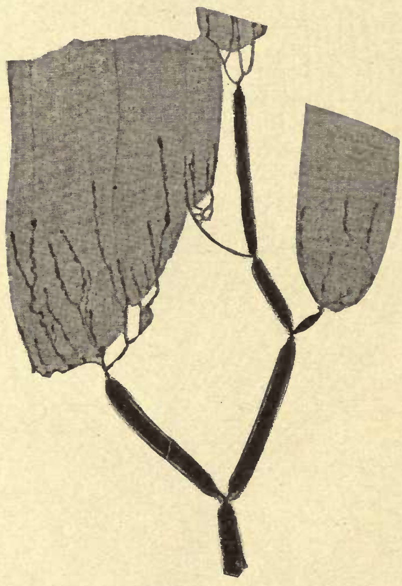


Fig. 40.—Sensory nerve terminating in arborizations around the ends of muscle-fibres. (Quain.)

Fig. 41.—An annulo-spiral ending of intrafusal fibre. Highly magnified. Methylene-blue preparation. (Quain.)

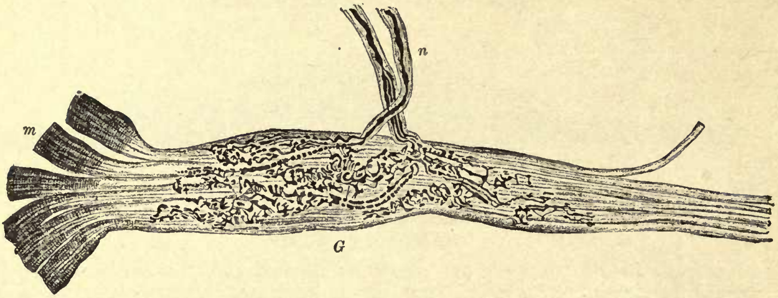


Fig. 42.—Organ of Golgi from the human tendo achillis. Chloride of gold preparation. (Quain.)

m, muscular fibres; *t,* tendon-bundles; *G,* Golgi's organ; *n,* two nerve-fibres passing to it.

Fig. 43.—Ending of nerve-fibres in cardiac muscle. (Quain.)

Fig. 44.—Motor nerve-ending in the abdominal muscles of a rat. Gold preparation. Magnified 170 diameters. (Quain.)

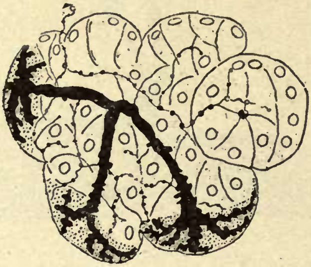


Fig. 45.—Terminal nerve-fibrils in an alveolus of the submaxillary gland of the dog. Chromate of silver method. (Quain.)
The extension of the lumen into the crescents of Gianuzzi is also shown.

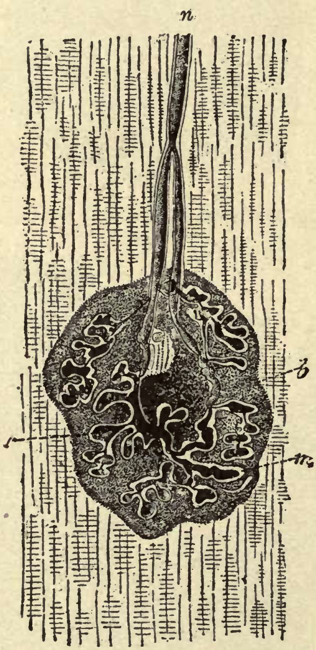


Fig. 46.—Motor end-organ of a lizard. Gold preparation. (Quain.)
n, nerve-fibre dividing as it approaches the end-organ; *r*, ramification of axis-cylinder upon, *b*, granular bed or sole of the end-organ; *m*, clear substance surrounding the ramifications of the axis-cylinder.

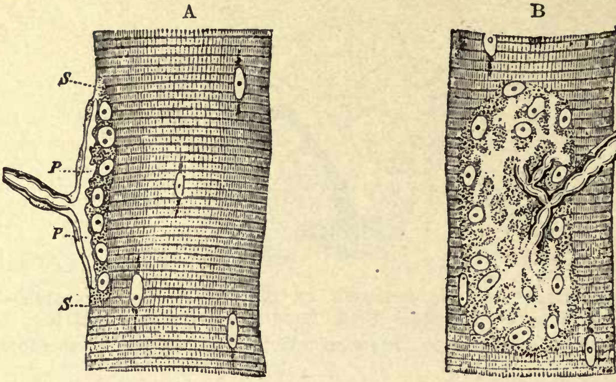


Fig. 47.—Nerve-ending in muscular fibre of lizard (lacerta viridis). (Quain.)

A, end-plate seen edgeways; *B,* from the surface; *s, s,* sarcolemma; *pp,* expansion of axis-cylinder. In *B* the expansion of the axis-cylinder appears as a clear network branching from the divisions of the medullated fibres.

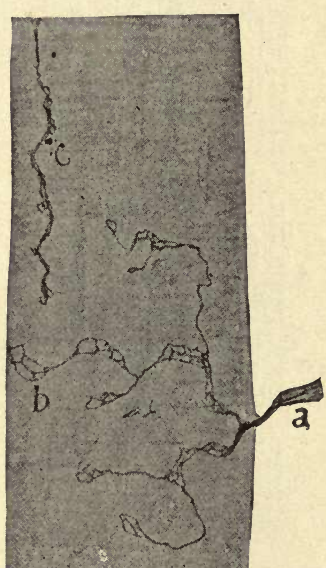


Fig. 48.—Ending of motor nerves in rabbit's muscle. Reduced silver method. (Quain.)

a, axis-cylinder of entering nerve; *b, c,* parts of terminal ramification showing network of neuro-fibrils.

epithelium containing fluid between them. These occur in the palms of the hands, the soles of the feet, in the parietal peritoneum, the mesentery, mammary gland, tendons, ligaments, joints, and penis, clitoris and in the voluntary muscles. (Fig. 38.)

7. Besides the Pacinian bodies sensory nerves to muscular fibers terminate in expansions which form (*a*) annular, (*b*) spiral and (*c*) arborizing expansions around the muscular fibers. (Figs. 39–41.)

8. Special arborizations upon the tendons are termed *organs of Golgi.* (Fig. 42.)

9. All motor nerves terminate at the muscular fibers by branching in a mass of granular substance superficial to the muscular fiber but beneath the sarcolemma. This ending is termed the motor end plate. All these modifications of endings have developed for the purpose of delicately transmitting slight molecular changes of a refined order to or from a sensitive cell. (Figs. 43–48.)

The more complex the connection between the termination of the nerve and the sensitive surface, the more refined and delicate and special is the sensation or motor impulse transmitted. In other words, in those regions in which sensations of a special sensitiveness or of a special kind must be transmitted there is need of a special device, which exists in the form of these complex nerve endings.

The importance of even simple nerve endings is made clear by the disorderly character of a reflex excited by stimulating the cut nerve endings after dissecting off the skin.

THE NERVOUS SYSTEM

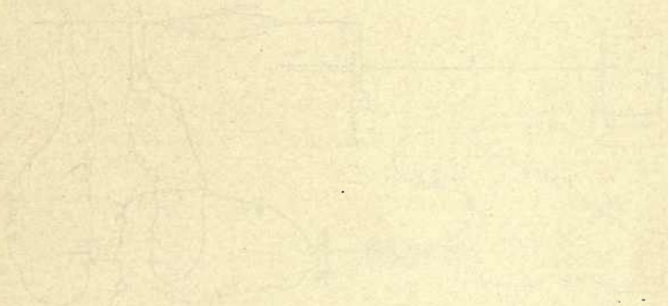
PHYSIOLOGY OF NERVES

The Classification of Nerves — Nerves may be classified as follows:—

- Efferent....
  - Excitatory
    - Motor
      - Motor
      - Vasomotor
      - Cardiomotor
      - Visceromotor
      - Pilomotor
    - Secretory
      - Salivary
      - Gastric
      - Pancreatic
      - Sweat
  - Inhibitory
    - Motor for all sub. div. of motor nerves
    - Secretory for all sub. div. of secretory nerves
  - Trophic
- Afferent....
  - Excitatory
    - Sensory
      - Visual
      - Auditory
      - Equilibrial
      - Olfactory
      - Gustatory
      - Pressure
      - Temperature
      - Pain
      - Hunger
      - Thirst
    - Reflex
      - Reflex for various efferent nerves
  - Inhibitory
    - Inhibitory upon conscious sensations have not been demonstrated
    - The reflex fibers which cause unconscious reflexes are known to be inhibited in some cases at least
  - Trophic

The Velocity of an Impulse along a Motor Nerve is measured by [illegible]

The interval between the time of application of the stimulus and the response [illegible] (Fig. 40.)



[illegible]

The Velocity of an Impulse along a Sensory Nerve can only be measured [illegible] electrical changes which accompany [illegible] motor nerve.

The velocity of propagation varies with the species of animals. [illegible]

The Direction of the Impulse. — The direction of propagation along a nerve fiber may be ascertained by noting the direction of [illegible] of the electrical current accompanying the propagation of the impulse. The impulse is found to travel in both directions from the point stimulated.

The Velocity of an Impulse along a Motor Nerve is measured by stimulation of the nerve of a muscular nerve preparation at two points, separated by a known distance, and recording upon a moving surface the time of application of each stimulus and the time of response (contraction of the muscle) to each stimulus.

The difference between the time of application of the stimulus and the response in the two cases will be the time it has taken the impulse to travel the known distance which separates the electrodes. The velocity in a frog's nerve is 28 meters a second, and in warm blooded animals is 60 to 120 meters a second. (Fig. 49.)

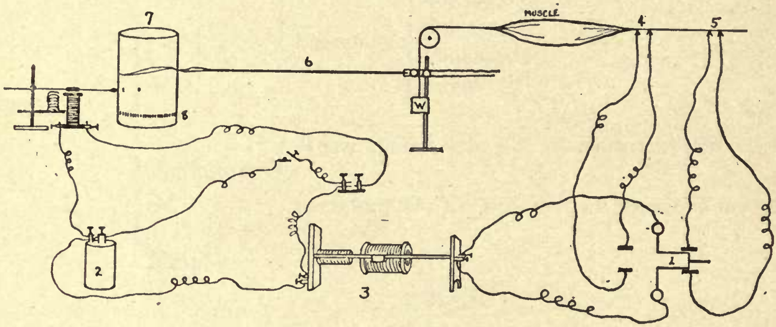


Fig. 49.—Apparatus arranged for determining speed of motor nerve impulse. By means of turn-over key (1), the current from the cell (2), through the inductorium (3) may be applied to the nerve at the two points (4 and 5). The difference in time in the contraction of the muscle is indicated by the difference in the rise of the lever (6) on the cylinder (7) in fractions marked at (8).

The Velocity of an Impulse along a Sensory Nerve can only be measured by measuring, in the same manner, the velocity of the electrical change which accompanies the propagation of the impulse. It is about the same as the velocity of propagation along a motor nerve.

The velocity of propagation varies with the species of animal. In general it is proportional to the height in the scale of life of the animal in question.

The Direction of the Impulses — The direction of propagation along a nerve fiber may be ascertained by noting the direction of spread of the electrical current accompanying the propagation of the impulse. The impulse is found to travel in both directions from the point stimulated.

A Demonstration that Nerve Impulses Travel in both Directions. — The gracilis muscle of a frog is separated incompletely into halves by a tendinous intersection. The axis cylinders supplying these two divisions are divisions of the same axis cylinders, which run to the muscle. Stimulation of the distal portion of the divisions of the axis cylinders supplying one half will cause a contraction of the whole muscle, whereas stimulation of the muscle alone, i.e., in a place free from nerve fibers, will cause a contraction in only one half of the muscle. In the first instance the impulse must have traveled up the set of axis cylinders of the stimulated part and down the branches into the unstimulated part, thus traveling in both the direction of the course of the nerve in the first and in the opposite direction to the course of the nerve in the other part.

Bell and Magendie's Law. — Though an impulse may travel in either direction of a nerve, the same nerve cannot be both afferent and efferent. This fact has been crystallized into a law by Bell and Magendie and is known as their law. The difference in the function of nerves expressed by the law of Bell and Magendie must depend, not upon any essential difference in the nerves, but solely upon their central and peripheral connections, a fact which may be demonstrated by grafting experiments.

Events Accompanying the Passage of a Nerve Impulse. — *The Dissipation of Energy.* — The fact that a nerve soon loses its irritability in the absence of oxygen indicates that the process of conduction is accompanied by the consumption of oxygen and, therefore, the dissipation of energy. The consumption of energy, however, must be extremely small since even the most sensitive methods for measuring heat have failed to detect any rise of temperature accompanying the passage of a nerve impulse.

The Demarcation Current. — If the terminals of a delicate galvanometer are connected to a resting uninjured nerve no current through the nerve will be detected. If, however, the nerve is injured and one of the galvanometer terminals is connected with the injured part, while the other pole is in contact with the side of the nerve at some distance from the injury, the galvanometer will swing, indicating in the first place the existence of a current in the nerve and in the second place that the current passes through the nerve from the end pole to the lateral pole. In terms of the electric potential the injured end of the nerve is negative to all

A Demonstration that Nerve Impulses Travel in both Directions — The gracilis muscle of a frog is separated longitudinally into halves by a tendinous intersection. The axis cylinders supplying these two divisions are divisions of the axis cylinders themselves, which run to the muscle. Stimulation of the distal portion of the divisions of the axis cylinders supplying one half will cause a contraction of the whole muscle, whereas stimulation of the muscle alone, *i.e.,* in a place free from nerve fibers, will cause a contraction in only one half of the muscle. In the first instance the impulse must have traveled up the set of axis cylinders of the stimulated half and down the branches into the unstimulated half, thus traveling in both the direction of the course of the nerve in one part and in the opposite direction to the course of the nerve in the other part.

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Events Accompanying the Passage of a Nerve Impulse — *The Expenditure of Energy* — The fact that a nerve loses its irritability in the absence of oxygen indicates that the process of excitation is accompanied by the consumption of oxygen and, therefore, the dissipation of energy. The consumption of energy, however, must be extremely small inasmuch as the most sensitive methods for measuring heat have failed to detect any rise of temperature accompanying the passage of a nervous impulse.

The Demarcation Current — If the terminals of a delicate galvanometer are connected to a resting uninjured nerve no current through the nerve will be detected. If, however, the nerve is divided and one of the poles of the galvanometer circuit is connected with the injured end, while the other pole is in contact with the side of the nerve at some distant point, the needle of the galvanometer will swing, indicating in the first place the existence of a current in the nerve and in the second place that the current passes through the nerve from the end pole to the lateral pole. In terms of the outside circuit the pole on the end of the nerve is negative to all

other points. This current is called a demarcation current and is excited by the injury to the nerve incidental to its division.

Current of Action — If now an impulse is excited in the nerve by stimulating it above the site of application of the poles of the galvanometer the needle of the galvanometer will swing in an opposite direction, indicating a current in the opposite direction. This current is the current of action or the current accompanying the passage of an impulse which passes from the stimulated point in both directions and consequently toward the injured end. It has been called the negative phase of the demarcation current. The demarcation current is strongest immediately after division of the nerve and quickly subsides as the nerve dies up to the node of Ranvier nearest to the cut end. It may again be excited by a fresh division above this node. The current of action travels with the same rate as the nervous impulse — 28-33 meters a second. It is 18 m. in length and lasts only 6/10,000-8/10,000 of a second at any one point.

Conditions Affecting the Passage of a Nervous Impulse — *Temperature* — Conduction along a nerve is much diminished by decreasing the temperature. A temperature between 0° and 5° C. is sufficient to check conductivity in a mammalian nerve. The temperature coefficient for each difference in temperature of 10° C. is 1.79. This amount is a constant factor by which the velocity of conduction along a nerve fiber may be multiplied to give the velocity at 10° C. higher temperature.

Fatigue — Nerve fibers cannot be fatigued, at least by excessive excitation, but a nerve muscular preparation quickly shows signs of fatigue from repeated excitation.

Demonstration of the Site of Fatigue in the Nerve Muscle Mechanism — After the preparation has been fatigued the muscle may be excited to contraction by direct stimulation, showing that the muscle, at least, is not the most quickly fatigued of the various components of a muscle nerve preparation. In considering the seat of fatigue of a nerve muscular preparation, besides the muscle, the motor end plate and the nerve are to be considered. Two agents will enable us to eliminate the nerve as the seat of fatigue. One is curare and the second is the passage of the constant current. Curare specifically paralyzes the motor end plate. If it is applied to a muscular nerve preparation the nerve may be con-

tinuously stimulated without affecting the motor end plate or the muscle, because of the block produced at the motor end plate by curare. After the effect of the curare wears off or after it is set aside by its antagonist physostigmin, the muscle again may be stimulated by stimulation of the nerve, showing that, although the nerve had been excited for a much longer time than would have been necessary to fatigue both the motor end plate and the muscle during the time that both were protected by the curare, the nerve is still capable of transmitting an impulse.

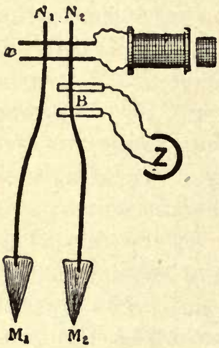

Fig. 50. — Indefatigableness of the nerves.

Two muscles, M_1, M_2, furnished with their nerves, N_1, N_2, are simultaneously stimulated at x by an induced current. The nerve, N_2, is anelectrotonized at B by a constant current, Z, so as to prevent the impulse reaching the muscle, M_2, thus to prevent this muscle being fatigued. The muscle, M_1, is quickly fatigued and ceases to contract. If then the cell current is broken, while the stimulation of the two nerves continues at x, the muscle, M_2, will be seen to contract; therefore its nerve has not felt the effects of fatigue.

A constant current possesses the power of blocking impulses through a nerve. It may be used in the same manner as curare to protect the motor end plate and muscle from excitation during a period of prolonged stimulation of the nerve of a nerve muscle preparation above the point of application of the constant current. (Fig. 50.)

Drugs — The action of drugs upon nerves may be tested by inclosing the nerve of a muscle nerve preparation within a closed tube. The nerve issues through the ends of the tube, which are closed with normal saline clay. Into the tube may then be conducted the vapor of the drug, the action of which it is desired to test. The effect of these drugs may then be tested upon both the excitability of the nerve and its conductivity.

Excitability may be tested by means of electrodes which make connections with the portion of the nerve inclosed within the tube.

Conductivity may be tested by electrodes making contact with a portion of the nerve outside of that end of the tube which is opposite to the end nearest the muscle end of the nerve muscle preparation.

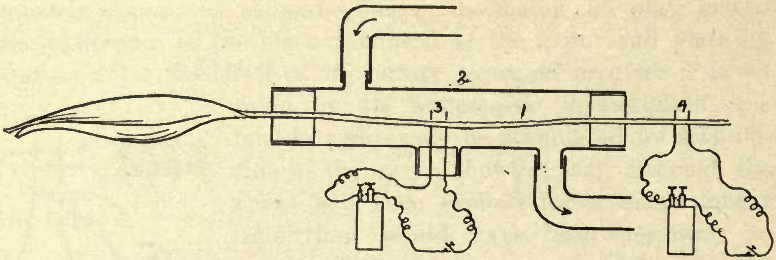

Fig. 51.—Apparatus for exposing a portion of a nerve to gases and for testing the excitability and conductivity of the exposed portion

1. Exposed portion of nerve.
2. Tube containing the gas with inlet and outlet.
3. Electrodes for testing excitability.
4. Electrodes for testing conductivity.

Effect of Carbon Dioxide and Ether, Chloroform and Alcohol—Carbon dioxide and ether diminish first excitability, and then conductivity. Chloroform rapidly diminishes excitability and conductivity and far more intensely than ether, so that recovery may not be complete. Alcohol diminishes conductivity without at first affecting excitability. (Figs. 51, 52.)

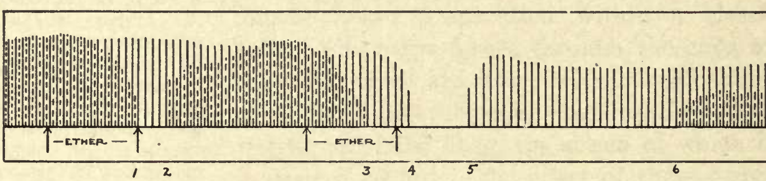

Fig. 52.—Illustrates the effect of ether vapor upon excitability and conductivity. Following the exposure of the nerve to ether there is a disappearance of excitability. The dotted vertical lines illustrate a response to the application of the current to the portion of the nerve surrounded with ether vapor. The straight vertical lines indicate a response of the nerve to the stimulation applied to a point outside the portion exposed to the ether vapor. The stimulus is therefore alternately applied to the nerve inside and outside of the tube.

At 1 there is a disappearance of excitability.
At 2 there is a reappearance of excitability.
At 3 there is a disappearance of excitability.
At 4 there is a disappearance of both excitability and conductivity.
At 5 there is a reappearance of conductivity and
At 6 a reappearance of excitability.

EVENTS ACCOMPANYING THE ELECTRICAL EXCITATION OF NERVES

The Minimal Effective Stimulus is ascertained by exciting a nerve-muscle preparation from the discharge of a condenser charged with decreasing potential until the minimal stimulus is found. (Fig. 33.) For frog's nerve it is 1/1000 of an erg (an erg being the amount of energy produced or work performed by the action of one dyne through one centimeter). A dyne gives an acceleration of one centimeter per second to one gram.

Summation.—If several subminimal stimuli are applied sufficiently close together so that each successive stimulus affects

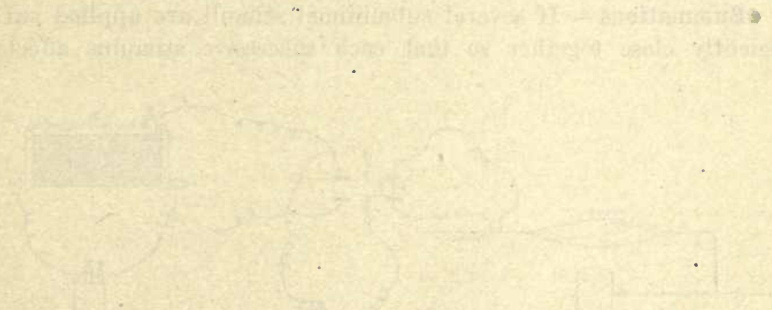

Fig. 33.—Illustrating the apparatus for exciting the nerve from a condenser charged to a definite quantity of electricity.

1, Switch for [illegible], 2, [illegible] the condenser, 3, [illegible] of the electrodes upon the nerve.

the nerve before the effect from the first one has passed off the combined effect may produce excitation though each individual stimulus would fail to do so. This phenomenon is called summation.

The Refractory Period.—For a brief time after the application of an electrical current to a nerve it remains unexcited. This period is called the refractory period and amounts to .002-.005 of a second according to the temperature. The existence of a refractory period is common to all forms of excitable tissue, and is best illustrated in heart muscle. After the application of a stimulus to heart muscle, the [illegible] contraction may be said to be progressing, and it is during this period that the muscle is refractory to another stimulus of the same strength, for the simple reason that it is already responding to the first stimu-

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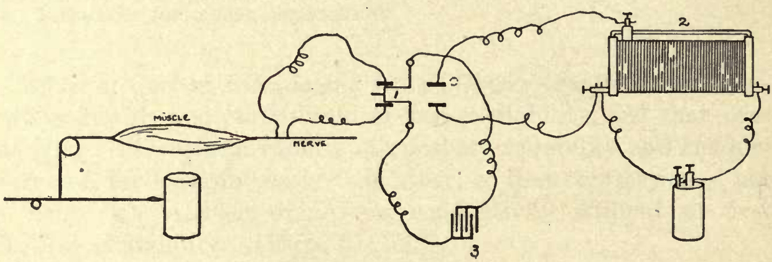

Fig. 53.—Illustrating the apparatus for exciting the nerve from a condenser with a definite quantity of electricity.

1. Switch for throwing, first, the rheostat, 2, and, second, the condenser, 3, into the circuit of the electrodes upon the nerve.

the nerve before the effect from the first one has passed off the combined effect may produce excitation though each individual stimulus would fail to do so. This phenomenon is called summation.

The Refractory Period — For a brief time after the application of an electrical current to a nerve it remains unexcited. This period is called the refractory period and amounts to .002-.0006 of a second according to the temperature. The existence of a refractory period is common to all forms of excitable tissue, and is best illustrated in heart muscle. After the application of a stimulus to heart muscle, the change producing contraction may be said to be progressing, and it is during this period that the muscle is refractory to another stimulus of the same strength, for the simple reason that it is already responding to the first stimu-

ies. If, however, a very strong stimulus is applied within the refractory period it may respond, so that the refractory period depends on the strength of the stimulus itself. However, after such a response it remains irresponsive to normal stimuli for a longer time, thus indicating the cause upon which the refractory period depends, namely a breaking down of material available for response, the response depending upon the katabolic changes.

Site of the Excitation.—When the constant current is made use of to excite a nerve an excitation occurs at the make and,

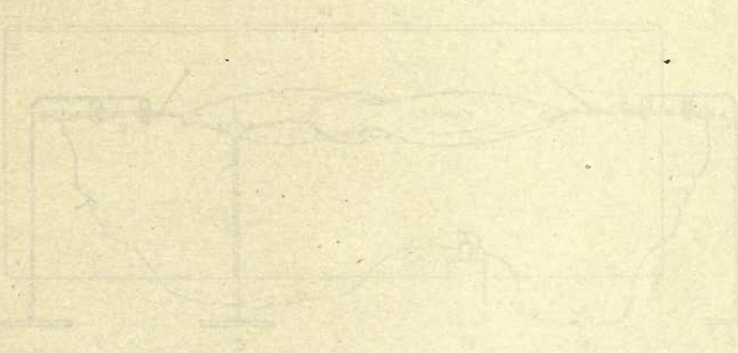

FIG. 33.—Apparatus for determining the site of excitation on the muscle, [illegible] at the anode or the cathode, at either the make or the break. B, Battery; K, key, by means of which the current is made or broken; C, clamp holding the muscle by its middle [illegible] electrodes [illegible] recording the movements upon the [illegible].

assuming that the current is strong enough, at the break also; the make excitation starts at the cathode and a break excitation starts at the anode. [illegible] a muscle [illegible] used to demonstrate this.

(a) It may be clamped tightly in the middle and the two electrodes attached to the two ends, each end being capable of moving towards the middle. At the make contraction the cathode side will swing in towards the middle, on the break contraction the anode will do the same. (Fig. 34.)

(b) [illegible] of one end of a muscle will prevent its [illegible] and may be used to demonstrate the starting point of the contraction at the make

lus. If, however, a very strong stimulus is applied within the refractory period it may respond, so that the refractory period depends on the strength of the stimulus used. However, after such a response it remains irresponsive to normal stimuli for a longer time, thus indicating the causes upon which the refractory period depends, namely a breaking down of material available for response, the response depending upon the katabolic changes.

Site of the Excitation — When the constant current is made use of to excite a nerve, an excitation occurs at the make, and,

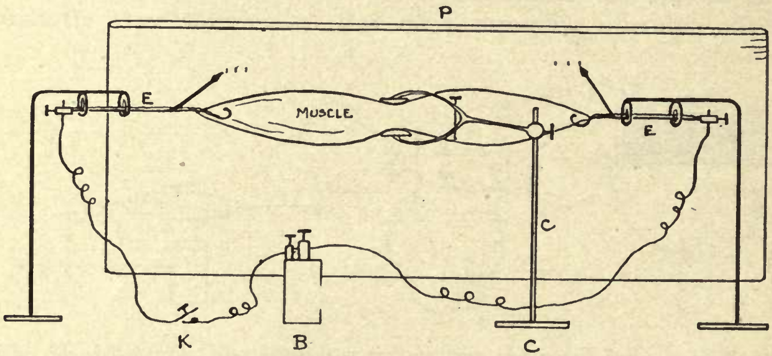

Fig. 54.—Apparatus for determining the site of excitation of the muscle, whether at the anode or the cathode, at either the make or the break. *B,* Battery; *K,* key, by means of which the current is made or broken; *C,* clamp holding the muscle by its middle movable electrodes, *EE,* capable of recording the movements upon the paper, *P.*

assuming that the current is strong enough, at the break also; a make excitation starts at the cathode and a break excitation starts at the anode. Inasmuch as what is true for one excitable tissue is true, in this respect, for another, muscle may be used to demonstrate the fact.

(a) It may be clamped lightly in its middle and the two electrodes attached to the two ends, each electrode being capable of a swing in towards the muscle. At the make contraction the cathode electrode will swing in towards the muscle; at the break contraction the anode will do the same. (Fig. 54.)

(b) Inasmuch as injury or death of the end of a muscle will prevent its irritability, a muscle injured at one end may be used to demonstrate the starting point of the contraction at the make

and break. At the make no contraction will occur if the cathode is attached to the injured end, and vice versa.

Electrotonus.—It has been said that contraction only occurs at the make and break of a constant current. If the current is strong enough the excitability of the nerve of a muscular nerve preparation may be so increased that the muscle may be thrown into a state of continued contractions, called closing tetanus, all the time during which the current is passing.

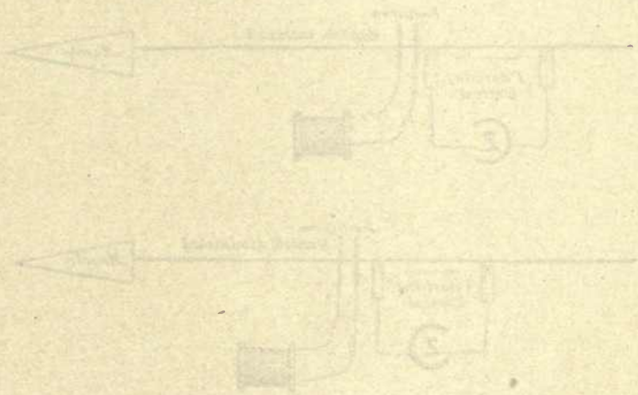

Fig. 33.—Determination of excitability of the myopolar segment during the passage of a current through a certain length of the nerve.

In the lower figure the polarizing current is ascending; excitability is diminished in the myopolar segment. In the upper figure the polarizing current is descending; the excitability of the myopolar segment is increased.

An "after tetanus" may also follow the break of a strong ascending current which has been passing for a considerable time. With moderate or usual currents, however, no apparent change occurs during the time the constant current passes.

Electrotonus and Method of Its Detection.—A change nevertheless does occur during the period between the make and break of a constant current which is capable of detection by stimulating different portions of the nerve by an induced current acting as an analyzer. During the time that the constant current is passing, the analyzer will detect a region near the cathode of the constant current where the excitability is increased, and hence a greater stimulus or impulse may be produced by a submaximal stimulus than would result in the absence of the constant current. In the same manner a region near the anode can be demonstrated in which the irritability is diminished. (Fig. 33.)

and break. At the make no contraction will occur if the cathode is attached to the injured end, and vice versa.

Electrotonus — It has been said that contraction only occurs at the make and break of a constant current. If the current is strong enough the excitability of the nerve of a muscular nerve preparation may be so increased that the muscle may be thrown into a state of continued contractions, called *closing tetanus,* all the time during which the current is passing.

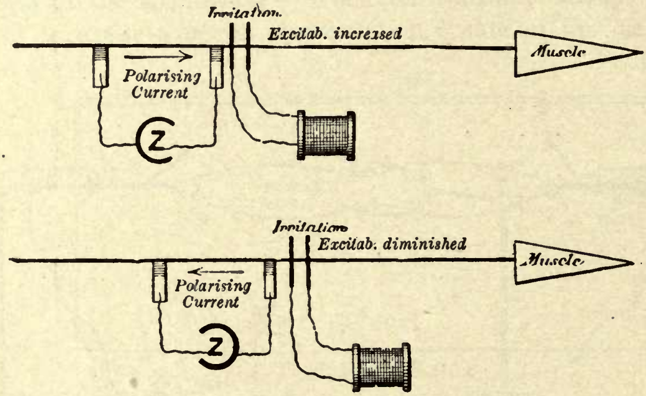

Fig. 55.—Determination of excitability of the myopolar segment during the passage of a current through a certain length of the nerve.

In the lower figure the polarizing current is ascending; excitability is diminished in the myopolar segment. In the upper figure the polarizing current is descending; the excitability of the myopolar segment is increased.

An *"after tetanus"* may also follow the break of a strong ascending current which has been passing for a considerable time. With moderate or usual currents, however, no apparent change occurs during the time the constant current passes.

Electrotonus and Method of Its Detection — A change nevertheless does occur during this period between the make and break of a constant current which is capable of detection by stimulating different portions of the nerve by an induced current acting as an analyzer. During the time that the constant current is passing, the analyzer will detect a region near the cathode of the constant current where the excitability is increased, and hence a greater stimulus or impulse may be produced by a submaximal stimulus than would result in the absence of the constant current. In the same manner a region near the anode can be demonstrated in which the irritability is diminished. (Fig. 55.)

Catelectrotonus and Anelectrotonus.—The increased irritability at the cathode is called catelectrotonus and the diminished excitability at the anode is called anelectrotonus. Inasmuch as the impulse leading to contraction at the make begins at the cathode it may be said that the excitability is due to a rise of irritability at the cathode, dependent upon the sudden development of catelectrotonus. In the same manner the rise of excitability at the anode accompanying the break is due to sudden passing off of anelectrotonus. The above is true for currents of moderate strength. When stronger currents are used the indifferent point separating the two regions of anelectrotonus and catelectrotonus from each other comes to lie nearer the cathode, so that more and more of the nerve is in a condition of anelectrotonus.

Pflüger's Law.—In the case, therefore, of very strong currents the whole intrapolar portion of the nerve is in a condition of anelectrotonus and the depression of irritability at the anode at the make is so great that the nerve is not conductive at this point. Consequently, when strong currents are used to produce stimulation, and the current is an ascending one, the impulse set free at the make, because the make excitation starts at the cathode, which is farthest from the muscle, in ascending currents is blocked by the high degree of anelectrotonus at the anode. In the same manner at the break of descending currents when strong currents are used the excitation started at the anode by the passing off of anelectrotonus cannot descend past the cathode where there is a return back from high catelectrotonus to a very low degree of irritability. These variations in the results of stimulating nerves with varying degrees of current have been formulated into a law called Pflüger's law, namely, that the result of stimulation of a nerve varies with the strength of the current and is as follows:

	ASCENDING		DESCENDING	
	make	break	make	break
weak	C	O	C	O
medium	C	C	C	C
strong	O	C or T	C or T	O

anelectrotonus block

C = strong contraction; c = contraction; T = tetanus; O = no effect.

Catelectrotonus and Anelectrotonus — The increased irritability at the cathode is called catelectrotonus and the diminished excitability at the anode is called anelectrotonus. Inasmuch as the impulse leading to contraction at the make begins at the cathode it may be said that the excitability is due to a rise of irritability at the cathode, dependent upon the sudden development of catelectrotonus. In the same manner the rise of excitability at the anode accompanying the break is due to sudden passing off of anelectrotonus. The above is true for currents of moderate strength. When stronger currents are used the indifferent point separating the two regions of anelectrotonus and catelectrotonus from each other comes to lie nearer the cathode, so that more and more of the nerve is in a condition of anelectrotonus.

Pflüger's Law — In the case, therefore, of very strong currents the whole interelectrodal portion of the nerve is in a condition of anelectrotonus and the depression of irritability at the anode at the make is so great that the nerve is non-conductive at this point. Consequently when strong currents are used to produce stimulation, and the current is an ascending one, no impulse can reach the muscle at the make because the make excitation starts at the cathode, which is furthest from the muscle. In ascending currents it is blocked by the high degree of anelectrotonus at the anode. In the same manner at the break of descending currents, when strong currents are used the excitation started at the anode by the passing off of anelectrotonus cannot descend past the cathode where there is a swing back from high catelectrotonus to a very low degree of irritability. These variations in the results of stimulating nerves with varying degrees of current have been formulated into a law called *Pflüger's law,* namely, that the result of stimulating a nerve varies with the strength of the current and is as follows:

	ASCENDING		DESCENDING	
	make	*break*	*make*	*break*
weak	c	O	c	O
medium	c	c	C	c
strong	O	C or T	C or T	O
	anelectrotonus block			

(C — strong contraction. c — contraction. T — tetanus. O — no effect.)

For these reasons, when dealing with induced shocks we are only dealing with make shocks. The contraction at the break of the primary circuit, which is evoked by the make of the make and break produced in the secondary circuit, is stronger than the contraction produced at the make of the primary, because the rise of current at the make in the primary is a much slower change than the fall of current at the break. In other words the intensity of the currents induced in the secondary coil is proportional to the rate of change of the current in the primary coil.

Application to the Human Being.—These results cannot be applied to human nerves with the same exactness, because of the

Fig. 58.—Diagram showing the general polarization of the nerve. All along the lines of the flow of the current, going from one pole to the other, secondary polarities are developed across the heterogeneous portions, followed by electrolytic conduction.

impossibility of the direct application of the electrodes to the human nerves. It is usual to apply one electrode, a stimulating effect being most readily obtained when the stimulating electrode is the cathode, over some point at which the various motor nerves lie nearest to the surface. The other electrode, the indifferent one, is applied over some other region of the body. Inasmuch as the current, as it nears the cathode, becomes concentrated from a more diffuse condition at a distance from the electrode, called the peripolar region, the current is strongest nearest to the electrode as it passes across the nerves. It exists as opposite signs on the two sides of the nerve and is stronger on the side nearest the cathode. (Fig. 58.) Pure cathode and anode effects are not obtainable. Applying the current in the manner described to the human being gives the following phenomena in the order of the strength of contraction produced:

For these reasons, when dealing with induced shocks we are only dealing with make stimuli. The contraction at the break of the primary circuit, which is evoked by the make of the make and break produced in the secondary circuit, is stronger than the contraction produced at the make of the primary, because the rise of current at the make in the primary is a much slower change than the fall of current at the break. In other words the intensity of the currents induced in the secondary coils is proportional to the rate of change of the current in the primary coil.

Application to the Human Being — These results cannot be applied to human nerves with the same exactness, because of the

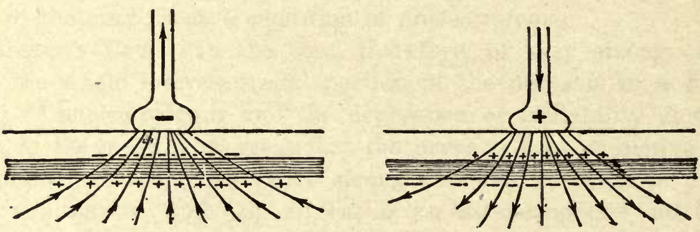

Fig. 56.—Diagram showing the internal polarization of the tissues. All along the lines of the flow of the current, going from one pole to the other, secondary polarities are developed across the heterogeneous portions, traversed by electrolytic conduction.

impossibility of the direct application of the electrodes to the human nerves. It is usual to apply one electrode (a stimulating effect being most readily obtained when the stimulating electrode is the cathode) over some point at which the various motor nerves lie nearest to the surface. The other electrode, the indifferent one, is applied over some other region of the body. Inasmuch as the current, as it nears the cathode, becomes concentrated from a more diffuse condition at a distance from this electrode called the peripolar region, the current is strongest nearest to the electrode as it passes across the nerves. It exists as opposite signs on the two sides of the nerve and is stronger on the side nearest the cathode. (Fig. 56.) Pure cathode and anode effects are not obtainable. Applying the current in the manner described to the human being gives the following phenomena in the order of the strength of contraction produced:

C. C. C. (Cathode closing contraction);
A. C. C. (Anode closing contraction);
A. O. C. (Anode opening, i.e., the break contraction);
C. O. C. (Cathode opening contraction).

Polarization and Its Explanation in the Extrapolar Region of the Nerve.—The length of a nerve between the electrodes of a current applied to the nerve is called the intrapolar or interelectrodal portion. By sensitive galvanometers it may be shown that a current passes also through the extrapolar regions of the nerve during the passage of a constant current. This current is in the direction of the constant current which is applied to the nerve. It

Fig. 38.—Polarization of the nerve in the two extrapolar regions and production of electrotonic currents in these two regions. The middle region is traversed by a constant current (polarizing current). The extrapolar regions show currents of polarization of the same direction as the polarizing, but opposed to it in magnitude. The anelectrotonic current is more intense than the catelectrotonic current.

is a different current from the current of action. This electrotonic current may be imitated by the application of a constant current to an artificial model of a nerve, consisting of a platinum wire suspended within a tube and surrounded within the tube by normal saline solution or any other electrolyte. It will not result, however, if the model is made of a zinc wire immersed in a saturated solution of zinc sulphate. The phenomenon of these extrapolar currents is, therefore, physical and depends upon polarization produced in the extrapolar regions of the nerve. The nerve sheath may be regarded as composed in part of a semipermeable membrane. (Fig. 38.)

Upon the sheath in the neighborhood of the positive pole of the polarizing current negative ions collect and in the same manner

C C C (cathode closing, i.e. make contraction)
A C C (anode closing contraction)
A O C (anode opening, i.e. the break contraction)
C O C (cathode opening contraction)

Polarization and Its Explanation in the Extrapolar Region of the Nerve—The length of a nerve between the electrodes of a current applied to the nerve is called the intrapolar or intraelectrodal portion. By sensitive galvanometers it may be shown that a current passes also through the extrapolar region of the nerve during the passage of a constant current. This current is in the direction of the constant current which is applied to the nerve. It

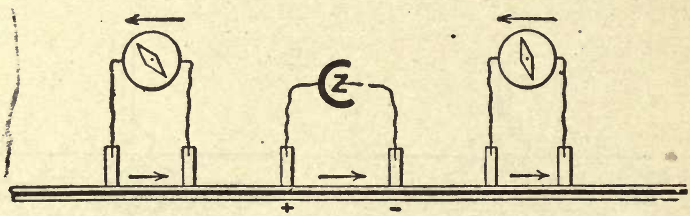

Fig. 56a.—Polarization of the nerve in its two extrapolar segments and production of electrotonic currents in these two segments.

The middle region is traversed by a constant current (polarizing current). The extrapolar regions show currents of polarization of the same direction as the preceding, but unequal in intensity. The anelectrotonic current is more intense than the catelectrotonic current.

is a *different current* from the current of action. The same extrapolar current may be excited by the application of a constant current to an artificial model of a nerve, consisting of a platinum wire contained within a tube and surrounded within the tube by normal saline solution or any other electrolyte. It will not occur, however, if the model is made of a zinc wire immersed in a saturated solution of zinc sulphate. The phenomenon of these extrapolar currents is purely physical and depends upon polarization produced in the extrapolar regions of the nerve. The nerve sheath may be regarded as composed in part of a solution electrolytes. (Fig. 56c.)

Upon the sheath in the neighborhood of the positive pole of the polarizing current negative ions collect and in the same manner

positive ions collect in the neighborhood of the negative pole. In fact it is only due to the fact that these two sets of ions are attracted to the poles and give up their charges to them that any current from the cell passes through the nerve at all. These attracted ions at the points of application of the electrodes create in this region a difference of potential which extends to the extrapolar region.

The Current of Positive Polarization and the Negative Variation.—In consequence of this fact a current will pass in the extrapolar region. This current is called the current of polarization (Fig. 30). If now the electrodes of the constant current are taken

Fig. 30.—Post-electrotonic polar currents produced after the cessation of the polarizing current.

I, polarizing current; II, negative post-current of contrary direction or the current of negative polarization; III, post-current whose direction is the same as that of the polarizing current or the current of positive polarization.

away from the nerve and in their place the poles of a galvanometer are applied, the galvanometer will show a temporary current in the opposite direction to that in which the constant current was previously flowing, though immediately preceding this current in the opposite direction there will be momentary current in the same direction. This momentary current in the same direction is known as the current of positive polarization, and that in the opposite direction as the current of the negative variation of the polarizing current. The current of positive polarization is really the current of action started by the break produced when the electrodes are lifted off. The negative variation of the polarizing current is due to the difference of potential created at the places where the poles of the constant or polarizing current had collected ions of unlike sign to that of the poles of the polarizing current in the region of the poles. Inasmuch as the ions thus collected at these spots are of unlike sign to that of the poles, the current will flow in the opposite direction to that of the polarizing cur-

positive ions collect in the neighborhood of the negative pole. In fact it is only due to the fact that these two sets of ions are attracted to the poles and give up their charges to them that any current from the cell passes through the nerve at all. These attracted ions at the points of application of the electrodes create in this region a difference of potential which extends to the extrapolar region.

The Current of Positive Polarization and Its Negative Variation — In consequence of this fact a current will pass in the extrapolar region. This current is called the current of polarization. (Fig. 56a.) If now the electrodes of the constant current are taken

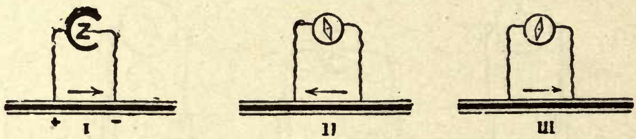

Fig. 56b.—Post-electrotonic intrapolar currents produced after the cessation of the polarizing current.

I, polarizing current; II, ordinary post-current of contrary direction or the current of negative polarization; III, post-current whose direction is the same as that of the polarizing current or the current of positive polarization.

away from the nerve and in their place the poles of a galvanometer are applied, the galvanometer will show a temporary current in the opposite direction to that in which the constant current was previously flowing, though immediately preceding this current in the opposite direction there will be momentary current in the same direction. This momentary current in the same direction is known as the current of positive polarization, and that in the opposite direction as the current of the negative variation of the polarizing current. The current of positive polarization is really the current of action excited by the break produced when the electrodes are lifted off. The negative variation of the polarizing current is due to the difference of potential created at the places where the poles of the constant or polarizing current had collected ions of unlike sign to that of the poles of the polarizing current in the region of the poles. Inasmuch as the ions thus collected at these spots are of unlike sign to that of the poles, the current will flow in the opposite direction to that of the polarizing cur-

rent. (Figs. 56b and 56c.) These currents of polarization are called electrotonic currents.

The electrotonic current excited in one of the two main branches

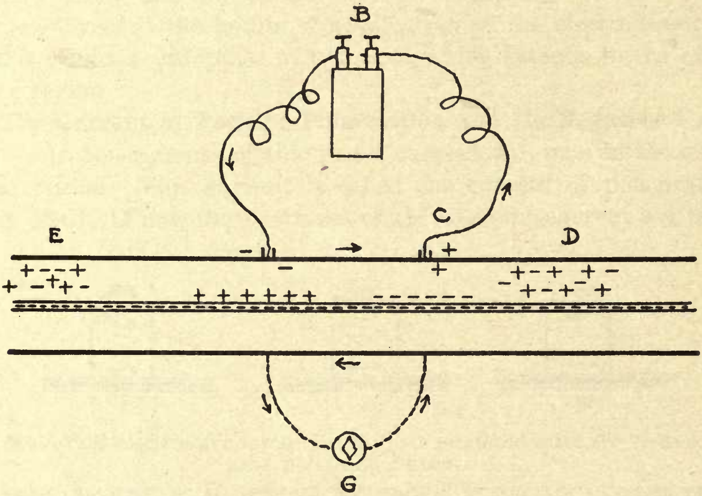

Fig. 56c.—Diagram illustrating the position of the ions which are responsible for the direction of the current of negative polarization indicated by the galvanometer, *G*.

When the current ceases to flow through the battery circuit, *B*, the collection of a larger number of positive ions in the neighborhood of the pole, *C*, causes the current to flow in the reverse direction through the galvanometer. The plus and minus signs, *D* and *E*, indicate the direction of extra polar electrotonic currents.

of a sciatic nerve is strong enough to excite an effective impulse in the other branch. This effect is not due to spreading of the current, as it will not occur if the stimulated branch is crushed.

THE PERIPHERAL NERVES

CONDITIONS AFFECTING ELECTRICAL STIMULATION OF THE NERVES

The Speed of the Make or Break — An apparatus has been devised which depends upon the rapid or slow opening of a shutter controlling the size of an opening between two concentrated solu-

tions of zinc sulphate in which is immersed electrodes of zinc and which is capable of more rapidly or slowly increasing the current. (Fig. 57.)

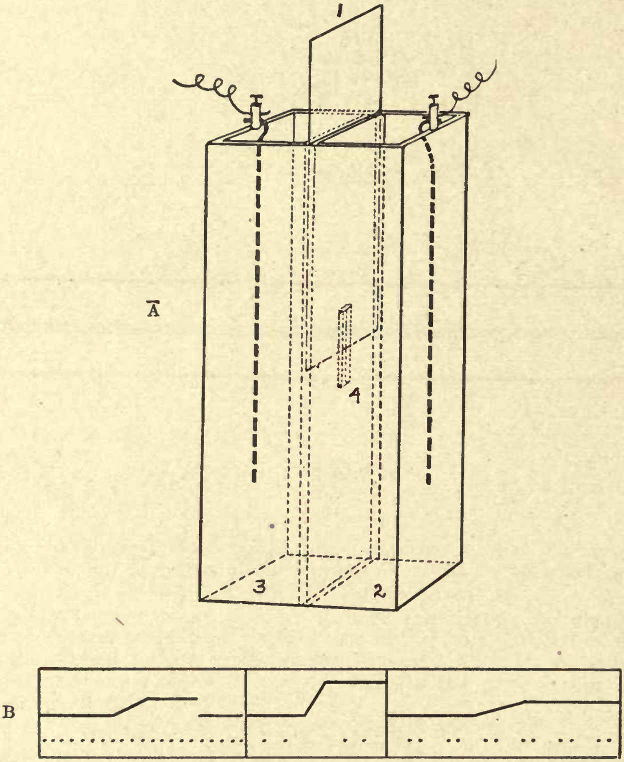

Fig. 57.—*A,* Diagram of Rheonome. By means of the shutter, 1, the speed of the make and break of the current between the electrolytes in the two boxes, 2 and 3, communicating only through the slit, 4, may be varied.

B, Illustrating the galvanometer records of the change of the current obtained by the differences of the speed of the make accomplished by the Rheonome.

The excitatory effect varies in proportion to the:

(1) Intensity of the current.

(2) And with certain limitations upon the rate of change of the current. Rapid alterations in the current, as in very rapid alterations of the induced current, are ineffective. It is for this reason that the high voltage of the Tesla current may be used for therapeutic effects upon the human being.

Waller's Characteristic — The optimum rate of change is known as Waller's characteristic. The rate of change may be recorded graphically and is called the current gratient.

The Duration of a Current which is used to produce excitation also bears important relations to the strength of excitation. This relation may be investigated by first ascertaining the minimal strength of current necessary to produce excitation and then determining how much the current must be increased as the time between the make and break is shortened to produce the same contraction.

Keith Lucas' Characteristic — Keith Lucas has used as a second characteristic that duration of the stimulus which will just produce an excitation when the strength of a minimal effective stimulus is just doubled. Each tissue, muscle, nerve and nerve ending as well as these various tissues in different animals have all their definite various characteristics.

The Effect of Temperature upon Excitability — Within certain limits the excitability of a nerve may be increased by cooling. Thus a frog's nerve cooled to 2° C. for a day will be so excitable that simple section of the nerve may be sufficient to throw it into a tetanus. This, however, is only true for mechanical stimuli. In the case of electrical stimuli warming of the nerve increases irritability and cooling diminishes it for all galvanic or induction shocks of less duration than .005 of a second. In the case of skeletal muscles excitability is increased by cooling for all forms of stimuli.

The reason why the time of .005 of a second is a factor in the effect of temperature on irritability is because the temperature produces two effects which do not vary at the same rate with changes of temperature. Thus cooling of a nerve both delays the subsidence of the excitatory process and renders more difficult the initiation of the excitatory change, but the delay in the subsidence of the excitatory process reduces the amount of current needed for excitation in an increasing ratio the longer the duration of the current, while increasing the difficulty of the initiation of the excitatory process such as is produced by (1) cooling, (2) prolonging the current, (3) delaying its subsidence, increases also the current required for excitation in the same ratio, or in an exponential ratio as the current is lengthened.

Effect of Injury on Irritability.—Immediately after injury there is an irritability near the site of injury, which is followed by diminution, progressing in a [illegible] direction, so that the portion nearest the injury is lowest in irritability.

Conduction of Nerve Impulse Across the Motor End Plate.—The [illegible] of the interval between the nerve and the muscle [illegible] a [illegible] to an impulse [illegible] more [illegible] stimulation. [illegible]

The Synaptic [illegible] at the [illegible].—[illegible]

Action of [illegible].—[illegible]

Specific Chemical Excitation Time of the Motor End Plate.—[illegible]

The [illegible]

Effect of Injury on Irritability — Immediately after injury a nerve is more irritable near the site of injury. After a time irritability diminishes progressively in a downward direction, so that the portion nearest the muscle is longest irritable.

Direction of Conductivity Across the Motor End Plate — The motor end plate, or the interval between the nerve and the muscle, constitutes a true synapse. Conduction across it is only possible in *one direction.* This is proved by the purely local contraction which is excited by snipping a nerve-free portion of a split muscle and contrasting the local contraction so excited with the contractions in both split portions when the ends of the nerves in one half are snipped.

The Specific Delay at the End Plate — A certain definite period of delay exists in the transmission of an impulse across a motor end plate. It has been found to be .0013 of a second. The motor end plate also shows fatigue more quickly than either the nerve or muscle, a fact also indicated by the specific action of curare and nicotine upon the motor end plate.

Action of Nicotine — *Nicotine,* after a primary stimulant action, has very much the same blocking effect upon the motor end plate that curare possesses, though it is much less powerful than curare. Four mg. of nicotine injected into the veins of a anesthetized fowl, will cause a tonic contraction of all the muscles, a phenomenon which may be immediately set aside by curare and one which can occur when enough nicotine has been given to paralyze all the motor nerves, or after all the motor nerves have degenerated in consequence of their having been previously sectioned. Thus nicotine, like curare, produces its effect by acting upon the substance of the motor end plates.

Specific Optimal Excitation Time of the Motor End Plate — A fourth fact demonstrating the different essence of the motor end plate is its different optimal excitation time. This represents the relation of the strength of the current to the duration of the current necessary to produce contraction. The muscle and the nerve and motor end plate all possess different optimal excitation times. The nerve-free end of the sartorious possesses an excitation time of .017 seconds, and this may be taken as the excitation time of the muscle.

The excitation time of the sciatic nerve trunk is about .003

second, and possesses a steeper gradient. That then is the excitation time of nerve fibers. In the middle of the sartorious muscle of the frog, in the region of the motor end plate, the excitation time is .00005.

The Neuromuscular Juncture of the Sympathetic Nerves and the Action of Adrenalin upon It — The sympathetic nerve fibers end seemingly in direct contact with the muscular fibers, without the intermediation of any motor end organ. Nevertheless there is evidence that here also there is present a third substance different from the nerve and muscle which bridges the gap between the two though it has not organization, at least of a motor end plate. Adrenalin possesses a specific stimulant action on the whole of that portion of the sympathetic nervous system which causes augmentation of function. Hence it contracts all blood vessels supplied by these nerves. Smooth muscle not innervated by the sympathetic nervous system as that of the blood vessels of the brain and lungs is unaffected by the injection of adrenalin. Therefore the action of adrenalin cannot be upon the muscular fiber itself. Adrenalin is just as effective, however, after complete degeneration of the post-ganglionic fibers of the sympathetic nerves, so that its action cannot be upon these post-ganglionic fibers themselves, but must be upon some third substance intervening between this fiber and the muscle. The same substance may be intermediary in all synapses and closely allied to the substance of the motor end plate. Its similar nature to the material of the motor end plate is suggested by the fact that injections of adrenalin act variously on skeletal muscle, forming a marked contrast to barium, which stimulates every skeletal muscle fiber in the body, acting upon them directly.

The Facts Indicating the Nature of an Excitatory Process — By the following facts *the nature of an excitatory process* in nerves is indicated:

(1) The dependence of irritability of a nerve upon a supply of oxygen demonstrating that there is an expenditure of energy even though in medullated fibers evidence of fatigue is absent. It is impossible to estimate any dissipation of energy in the form of heat. Non-medullated fibers can be fatigued.

(2) The failure of the decrement in the excitatory process as it becomes transmitted.

(3) The excitatory state is attended with an electrical change

of such a nature that an excited spot is negative to all other spots. The electrical change rises to a maximum rapidly and dies away slowly. The amount of rise and fall is dependent upon the tissue under investigation.

(4) The excitatory change is aroused only at the poles of a current passing through the tissue, *i.e.,* at the places where the collection of ions is greatest.

(5) Excitation occurs only at the cathode at the make and, only, if the current attains sufficient strength within a certain length of time.

(6) All living tissues are made up of colloids divided into compartments by membranes of various permeabilities and permeated with salts and various electrolytes in solution. Very many possibilities, therefore, exist for the formation of successive compartments characterized by large differences in potential. We may conceive of a successive transmission of such electrical states, and of such a movement of the ions, along a successive series of compartments in a nerve fiber as will account for large differences in potential. The process may be roughly likened to the explosion of a successive chain of equal masses of gunpowder. The number of variables affecting the movement of the ions are numerous and will permit of many possibilities.

THE SPINAL CORD

MORPHOLOGY

[illegible]

II

THE SPINAL CORD

MORPHOLOGY

Its Structure from a Development Standpoint — In certain orders of invertebrates the whole central nervous system is composed solely of ganglia united by nerve strands. These simpler nervous systems are, therefore, segmental in character. Even in the embryo of mammals the first traces of the nervous system are segmental. In the fully developed nervous system of mammals all trace of the segmental character of the nervous system is lost except as it is represented by the regular manner in which the spinal nerves leave the spinal cord.

Gross Anatomy of the Spinal Cord — The spinal cord is approximately *eighteen inches long.* (Fig. 58.) From its lateral surfaces are given off *thirty-one pairs* of nerves. Each pair is composed of an anterior and posterior root which emerges from the spinal canal through the intervertebral foramen. On each posterior root, before it joins the anterior root in its passage through the intervertebral foramen, is a large ganglion through which the posterior root passes. The anterior roots arise by a series of fasciculi spread out over a rather considerable length of the particular level of the cord from which the root arises. The posterior root arises as a single well-marked bundle.

On section of the cord it is seen to be composed of a peripheral white substance and a central gray substance. The central gray substance is shaped somewhat like an H, and possesses in other words two anterior horns and two posterior horns connected with a transverse bar of gray matter. (Fig. 59.) In the center of this transverse bar is a central canal. The white matter owes its color to the fact that it is composed of medullated nerve fibers. The gray matter is darker because within it are contained the nerve cells of the spinal cord. Each lateral half of the spinal cord is separated

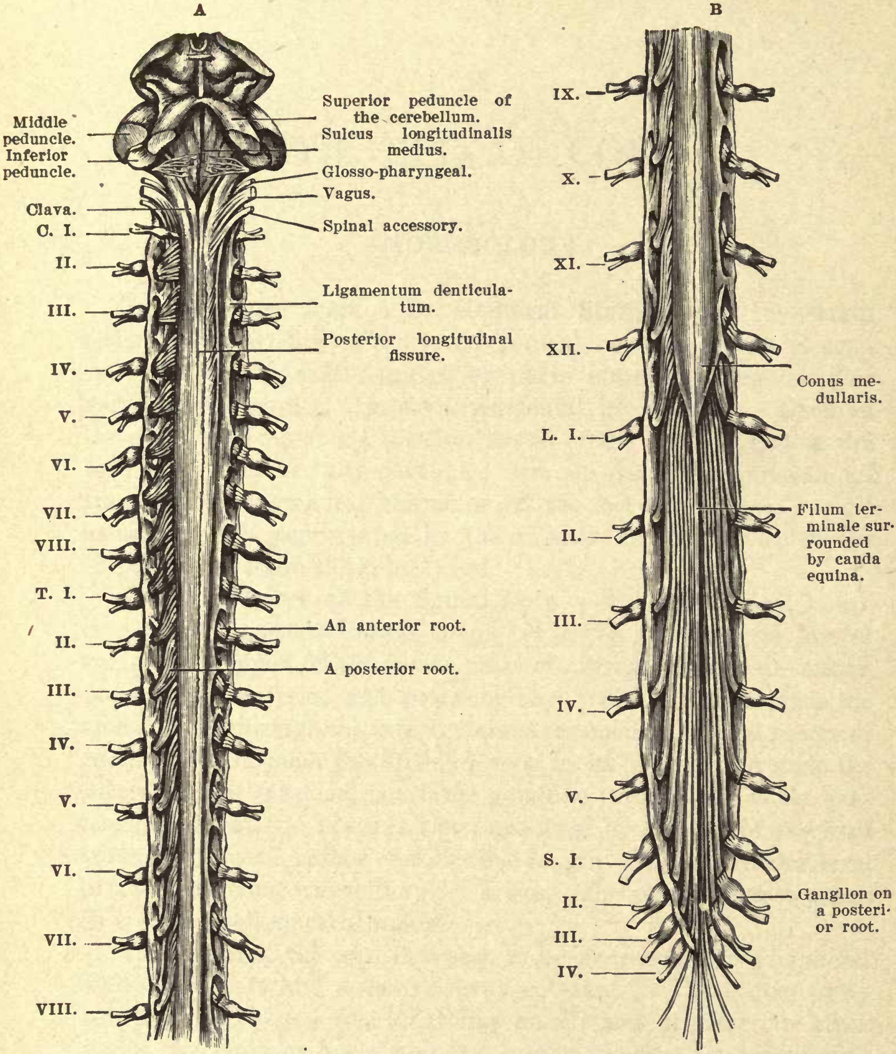

Fig. 58.—Dorsal aspect of the medulla oblongata and spinal cord with the dura mater partially removed. (Morris.)

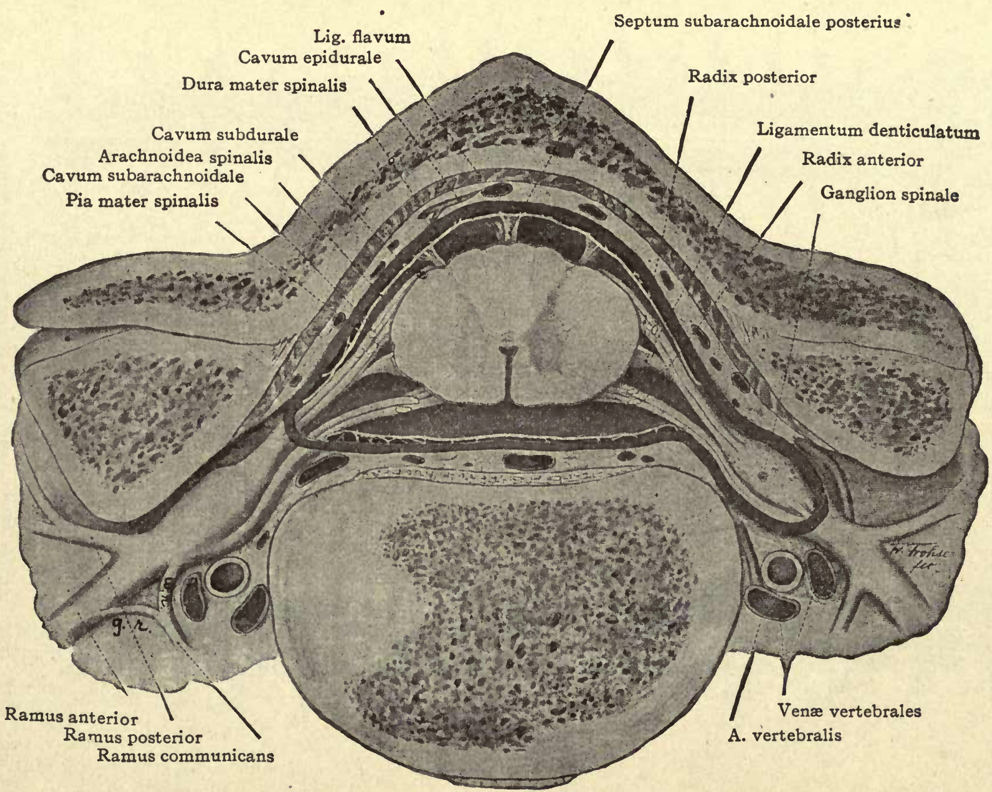

Fig. 59.—Transverse section through the fourth cervical vertebra, showing the coverings of the cord. *g. r.*, gray ramus communicans; *w. r.*, white ramus communicans. (Bailey.)

from the other by a deep anterior and posterior fissure which reaches nearly to the central transverse bar of gray matter. At the bottom of these fissures are strands of transverse white fibers.

These are the anterior and posterior commissures. The amount of central gray matter at any level of the spinal cord is in proportion to the number of nerve fibers coming off at that particular level. The amount of white matter diminishes progressively from above downwards. The size of the transverse section of the cord is greatest in the cervical region, that region supplying the upper limbs and containing all the fibers in the white matter to and from the dorsal and lumbar regions as well.

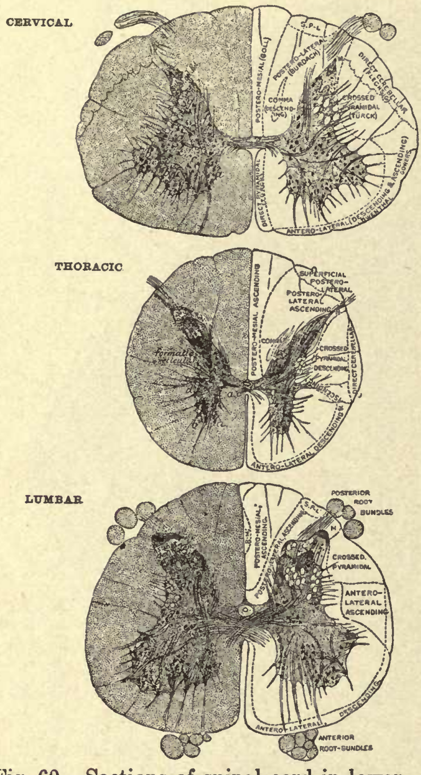

Fig. 60.—Sections of spinal cord in lower cervical, mid-thoracic, and mid-lumbar regions. (Quain.)

On the right side of each section conducting tracts are indicated. *P.-M.'* (in the lumbar region), septo-marginal tract.

The cord is smallest in the dorsal region and again enlarges in the lumbar region though smaller here than in the cervical region. The enlargement in the lumbar region is dependent entirely upon the large amount of gray matter, the axons of which supply the lower limbs. (Fig. 60.)

The Group of Nerve Cells — The nerve cells of the gray matter are collected into certain groups. (Fig. 61.) Of the anterior horn there are:

1. *A median group.* Many of the processes of this group cross the middle line.

2. *An external group* of large multipolar cells whose axons enter directly the anterior nerve roots.

3. At the base of the anterior horn, in a region which may be

[illegible] the lateral horn, is a group of round cells whose fibres [illegible] enter the anterior roots, forming the motor nerve fibres of these roots and belonging to the [illegible].

4. In the posterior horn are the [illegible] scattered but a [illegible] collection of cells [illegible] of the posterior horn [illegible] its mesial side. It is known as Clarke's column of cells.

[illegible]

The cells of the gray matter of the spinal cord may be classified from their functional standpoint:

1. Motor cells, chiefly the [illegible] of the anterior horn.

2. Cells of the [illegible]. The cells of Clarke's column [illegible] in the [illegible] of the white matter of the spinal cord.

3. Commissural cells whose axons cross to the opposite side of the cord.

4. Cells of Golgi, characterized by a large [illegible] which are [illegible] the cells [illegible].

The [illegible] of the [illegible] the System of Neurons [illegible] of the spinal cord [illegible].

termed the lateral horn, is a group of small cells whose fibers also enter the anterior nerve roots, forming the smaller nerve fibers of these roots and belonging to the sympathetic nervous system.

4. In the posterior horn the nerve cells are more scattered but a very well-marked collection of cells exists at the root of the posterior horn near its internal side. It is known as *Clark's column of cells.*

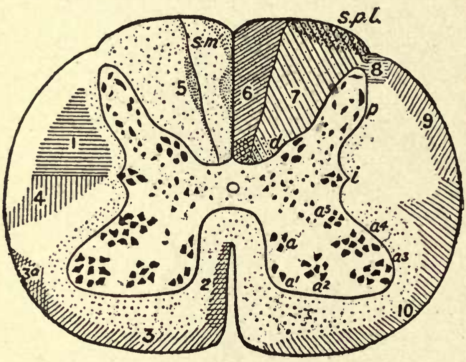

Fig. 61.—Diagram showing on the right side the "ascending" and on the left side the "descending" tracts in the spinal cord.

1, Crossed pyramidal; 2, direct pyramidal; 3, antero-lateral descending; 3*a,* bundle of Helweg; 4, prepyramidal; 5, comma; 6, postero-mesial; 7, postero-lateral; 8, marginal; 9, dorsal cerebellar; 10, antero-lateral ascending or ventral cerebellar; *s-m,* septo-marginal; *s. p. l.,* superficial postero-lateral fibres (dorsal root-zone of Flechsig); *a* to a^5, groups of cells in the anterior horn; *i,* intermedio-lateral group or cell-column in the lateral part of the grey matter; *p,* cells of posterior horn; *d* dorsal nucleus or cell-column of Clark. The dots represent "endogenous" fibres (arising in grey matter of cord) having for the most part a short course.

The cells of the gray matter of the spinal cord may be classified from their functional standpoint as:

1. Motor cells, chiefly the antero-lateral cells and the cells of the anterior horn.

2. Cells of the columns. The cells of Clark's column, because their axons form a definite column in the lateral regions of the white matter of the spinal cord.

3. Commissural cells whose axons cross to the opposite side of the cord.

4. Cells of Golgi, represented by a large number of the cells of the posterior horn which are multipolar and whose axons do not travel far from the cell but rapidly break up into dendrites. They are, therefore, chiefly associative in function.

Significance of the Connections of the System of Neurons— For a proper understanding of the functions of the spinal cord a knowledge of the connections of the tracts which form systems of neurons is absolutely essential.

[illegible]

Methods for Treating the System of [illegible]

[illegible]

[illegible]

Methods for Tracing the System of Neurons —

a. By intravital staining.

b. By the impregnation method of Golgi. This method accomplishes the impregnation of the neurons by a silver salt which blackens on exposure to light. The feature which makes this method of value is the fact that the impregnation is not general. In virtue of this fact sections of considerable thickness, containing a long distance of any nerve fiber, may be studied.

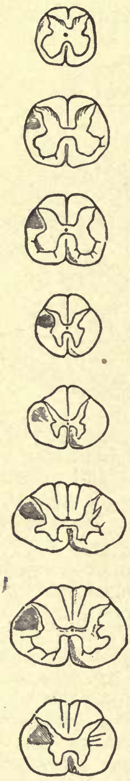

Fig. 62.—Diagram showing the descending degeneration of the pyramidal tract following a lesion in the left cerebrohemisphere involving the Rolandic area.

c. Myelination Method — As the nervous system develops the nerve fibers become inclosed in their myelin sheaths. The various systems of neurons do not acquire their sheaths at the same period. The tracts, which develop phylogenetically later, that is the youngest tracts, acquire their myelin sheaths later and may hence be recognized by stains which bring out the myelin sheath, such stains when applied at an early period of their development failing to render them conspicuous as compared to the other surrounding tracts.

d. The Wallerian Method — A nerve fiber which is divided degenerates away from the nerve cell of which the fiber may be an axon. Whole tracts of nerve fibers may, therefore, degenerate when they come from the same area of gray matter. (Fig. 62.) As a result of this degeneration fatty products are formed in the myelin sheath of the degenerated nerves which take an intense black stain with osmic acid. At a period of three weeks after the tract has been divided it will appear black; at the end of six months these products will be removed and the degenerated tract will take no stain at all. At this stage it will also contrast strongly with the undegenerated tracts which stain normally. (Fig. 63.)

e. Method of Retrograde Degeneration — If an axon is divided at a point distal to its cell, a certain degree of degeneration will

appear in the cell for a period of a few weeks, after which such a cell will again regain its normal staining power.

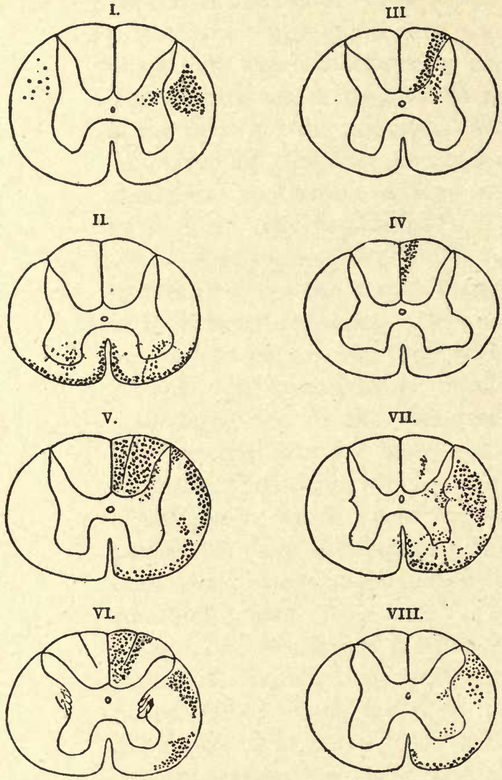

Fig. 63.—Diagram of sections of the spinal cord of the monkey, showing the position of degenerated tracts of nerve-fibres after specific lesions of the cord itself, of the afferent nerve-roots, and of the motor region of the cerebral cortex. The degenerations are shown by the method of Marchi. The left side of the cord is in all cases on the reader's left hand. (Quain.)

I. Degenerations resulting from extirpation of the motor area of the cortex of the left cerebral hemisphere.

II. Degenerations produced by section of the dorsal longitudinal bundles in the upper part of the medulla oblongata.

III. and IV. Results of section of dorsal roots of the first, second, and third lumbar nerves on the right side. III. is from the segment of cord between the last thoracic and first lumbar roots; IV. from the same cord in the cervical region.

V. to VIII. Degenerations resulting from (right) semi-section of the cord in the upper thoracic region. V. is taken a short distance above the level of section; VI. higher up the cord (cervical region); VII. a little below the level of section; VIII., lumbar region.

The same degenerative changes may, however, represent [illegible] motor cell from a section of [illegible]. [illegible] generation is probably, therefore, a degeneration of [illegible] and [illegible] used in the tracing out of nerve tracts with much success.

PHYSIOLOGY

THE MOTOR AND SENSORY PATHS TO AND FROM THE CORD

The Functions of the Anterior Nerve Roots and Method of Investigating Them.—If the anterior nerve root of [illegible] be cut, a paralysis of certain muscles [illegible]. If the central end of the root is stimulated no effects will be produced. If, on the other hand, the peripheral end is stimulated, certain muscles will contract.

If the anterior roots of the [illegible] region [illegible] effects will be produced by peripheral stimulation. Dilatation of the pupils, or constriction of certain blood vessels, or acceleration of the heart beat, are amongst these [illegible] effects.

The Functions of the Posterior Roots.—Section of the posterior nerve roots will be followed by loss of sensation [illegible]. Stimulation of the peripheral end is also without effect.

Stimulation, however, of the central end of the posterior roots [illegible] the sensation of pain. If the spinal cord has been divided [illegible] movements. If two or three posterior nerve roots have been divided there will be anaesthesia over definite areas of the surface.

The motor and sensory roots, therefore, are respectively [illegible] efferent [illegible], i.e. the pathway [illegible] the spinal cord, and the pathway into the spinal cord.

The Peripheral Distribution of the Anterior Roots, and the Function of the [illegible].—Each [illegible] of the motor [illegible] of the spinal cord. [illegible] of the motor [illegible] muscles [illegible]. The [illegible] nerve [illegible] the spinal [illegible]. From these plexuses the

The same degenerative changes may, however, appear in a motor cell from a section of posterior nerve root. Retrograde degeneration is probably, therefore, a degeneration of disuse and must be used in the tracing out of nerve tracts with much caution.

PHYSIOLOGY

THE EFFERENT AND AFFERENT PATHS TO AND FROM THE CORD

The Functions of the Anterior Nerve Roots and Method of Investigating Them — If the anterior nerve root is divided there will result a paralysis of certain muscles. If the central end of the root is stimulated no effects will be produced. If, on the other hand, the peripheral end is stimulated certain muscles will contract.

If the anterior root is one of the thoracic roots, certain visceral effects will be produced by peripheral stimulation. Dilatation of the pupils, or constriction of certain blood vessels, or augmentation of the heart beat, are among these visceral effects.

The Functions of the Posterior Roots — Division of one posterior nerve root will usually produce no noticeable effect. Stimulation of its peripheral end is also without effect.

Stimulation, however, of its central end in the conscious animal will produce signs of pain. If the spinal cord has been divided beneath the brain, central stimulation will produce reflex movements. If two or three posterior nerve roots have been divided there will be anesthesia over limited areas of the surface.

The anterior roots must, therefore, be regarded as entirely efferent in their function, *i.e.*, as the pathway out from the spinal cord, the posterior roots as entirely afferent and the pathway into the spinal cord.

The Peripheral Distribution of the Anterior Roots, and the Function of the Plexuses — Each muscle of the limbs receives nerve fibers from more than one *segment of the spinal cord.* Hence stimulation of one anterior nerve root in a peripheral direction does not produce contraction of any one muscle or one physiological group of muscles. The anterior nerve roots passing from that region of the spinal cord which supplies the limbs unite after leaving the spinal cord to form *plexuses.* From these plexuses the

[illegible] nerve-roots or which supply groups of muscles which are physiologically related.

[illegible] comparison of [illegible] reveals [illegible] that the range of [illegible] and area of muscles which are physiologically related.

The Function of the Ring Fibres.—A section of a thoracic posterior nerve-root shows it to be composed of large and small fibres. The large fibres are axons of the large cells in the lateral portion of the posterior horn and [illegible] of the muscles.

The fine fibres are axons of the cells in the [illegible] and pass in the white [illegible] communicate to the sympathetic system. These fibres transmit impulses [illegible] dilatation of the pupils, acceleration of the heart beat, contraction of the blood vessels, inhibition of movements of [illegible] of hairs.

1. **The Immediate Fate of the Fibres of the Posterior Nerve Roots.**—The fibres of the posterior roots pass directly into the spinal cord, divide into an ascending branch and descending branch.

(a) *Lissauer's Tract.*—The [illegible] forms a tract near the tip of the posterior horn, [illegible] bundle. The fibres in this tract are short and terminate in [illegible] of the substantia gelatinosa of the tip of the posterior horn.

(b) *The Columns of Goll and Burdach.*—The ascending fibres are long. A large number of these pass directly into the posterior white columns of the cord. In [illegible] the region between the posterior horns and the posterior median fissure. The [illegible] fibres ascend through the whole length of the cord, and as they ascend they occupy a more median position, [illegible] by the fibres entering at higher levels. (Fig. [illegible].) The [illegible] part of the posterior column is called the column of Goll, the [illegible] part is called the column of Burdach. [illegible] Other ascending fibres terminate at [illegible] in the posterior horn. [illegible] of the long fibres give off collaterals to cells at different levels of the spinal cord. The fibres forming Burdach's column are [illegible] of the [illegible] posterior roots.

(c) Fibres ending in the cell groups of the gray matter. These fibres occupy a position in the posterior root between the fibres of the [illegible] posterior columns and those of Lissauer's column.

single nerves come off which supply groups of muscles which are physiologically related.

Stimulation of one of these nerves, therefore, causes a contraction of one muscle or one group of muscles which are physiologically related.

The Function of the Fine Fibers — A section of a thoracic anterior nerve root shows it to be composed of large and small fibers. The large fibers are axons of the large cells in the lateral region of the anterior horn and run to the muscles.

The fine fibers are axons of the cells in the lateral horns and pass as the white rami communicates to the sympathetic system. These fibers transmit impulses which cause dilatation of the pupils, augmentation of the heart beat, contraction of the blood vessels, inhibition of movements of the intestines and erection of hairs.

1. The Immediate Fate of the Fibers of the Posterior Nerve Roots — The fibers of the posterior roots pass directly into the spinal cord, divide into an ascending bundle and descending bundle.

(a) *Lissauer's Column* — The descending bundle forms a tract near the tip of the posterior horn. It is known as *Lissauer's column.* The fibers of this tract are short and terminate in cells in the substantia gelatinosa at the tip of the posterior horn.

(b) *The Columns of Goll and Burdach* — The ascending fibers are long. A large number of them pass upwards in the posterior white columns of the cord, *i.e.,* in the region between the posterior horns and the posterior median fissure. In these columns the fibers ascend through the whole length of the cord, and as they ascend they occupy a more median position, making room in this manner laterally for other fibers entering at higher levels. (Fig. 64.) The external half of this posterior column is called the *column of Burdach,* the internal bundle is called the *column Goll.* Both are well marked in the cervical region. Other ascending fibers terminate at different levels of the spinal cord around cell in the posterior horn. All of the long fibers give off collateral fibers to cells at different levels of the spinal cord. The fibers forming these long tracts are the most internal of the fibers of the posterior root.

(c) Fibers ending in the cell tracts of the gray matter. These fibers occupy a position in the posterior root between the fibers of the long posterior columns and those of Lissauer's column.

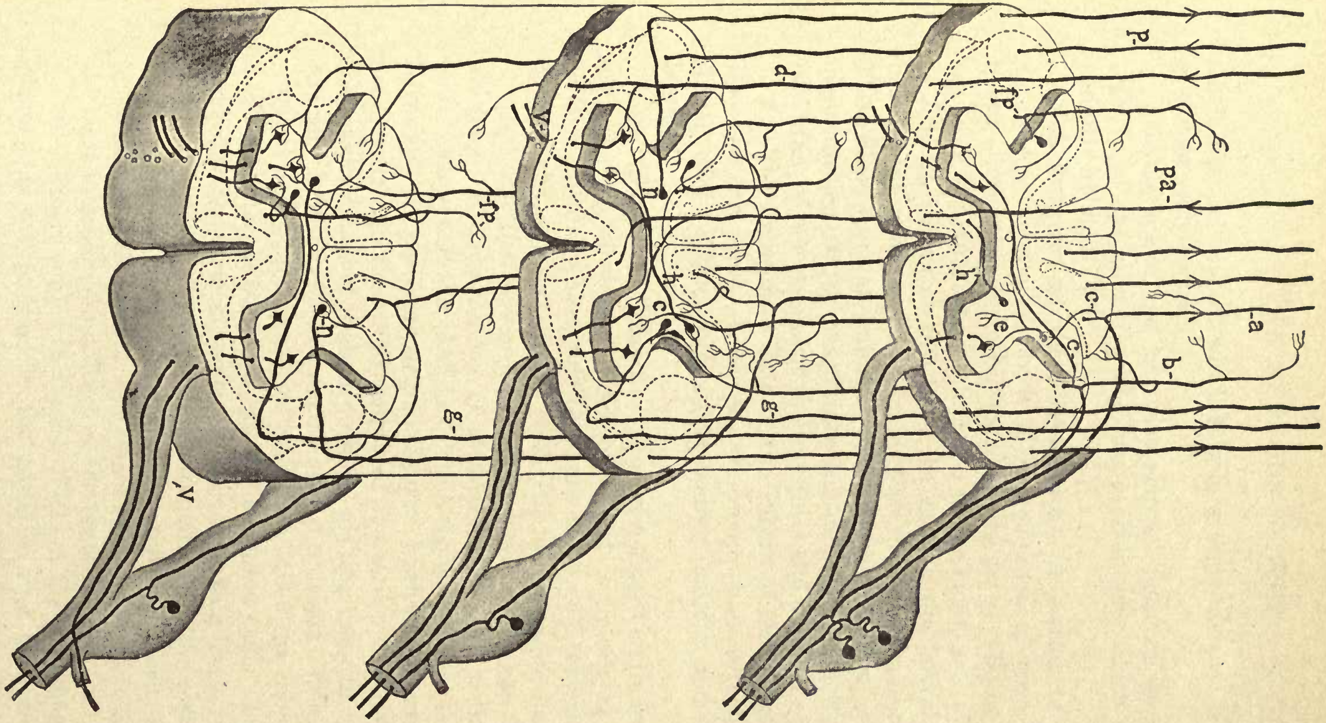

Fig. 64.—Schematic representation of the more important architectural relations of neurons in the spinal cord, omitting those involving the mesencephalon and thalamus.

a, afferent (spinal ganglion) nerve of spino-cerebral chain with bifurcation and caudal branch; *b*, afferent axon coursing the Lissauer's zone and distributed wholly within the cord; *c*, collaterals of *a* and *b* disposed in three ways; *p*, pyramidal axon in lateral (crossed) cerebro-spinal fasciculus distributed to levels of gray substance; *pa*, axon in ventral cerebro-spinal fasciculus decussating before termination; *v*, ventral root or motor neurons; *n*, nucleus dorsalis giving axon to dorsal spino-cerebellar; *g*, ascending neurons of Gowers' tract; *d*, descending axon from cerebellum (probable); *fp*, neurons of fasciculi proprii, association proper; *h*, commissural neurons; *e*, Golgi cell of type II. (Morris.)

Five groups are traceable. (Figs. 64, 66, 67 and 68.)

1. Fibers to the cells of the posterior horn of the same side.

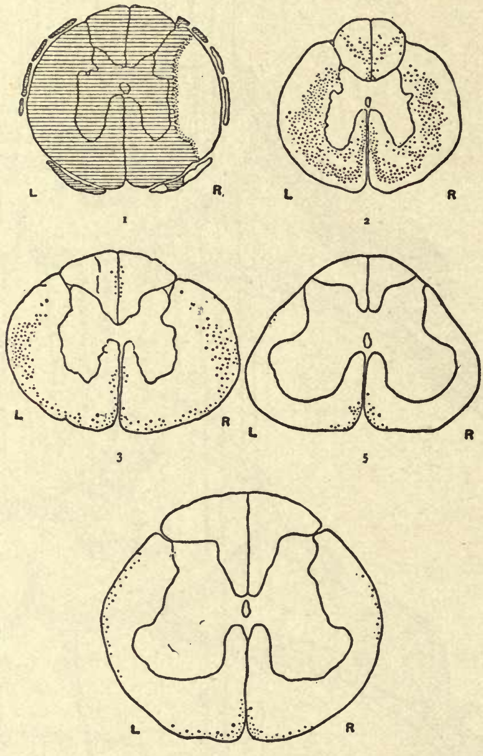

Fig. 65.—Cross-sections of the spinal cord of the dog revealing the position of the nerve-tracts descending to the hind-limb region from origin in the foremost three thoracic segments, by the method of "successive degeneration."

The eighth cervical segment had been exsected and 568 days later a crosscut was made at the hindmost level of the third thoracic segment. The transverse extent of this lesion, as determined by microscopic sections afterwards, is shown in diagram 1 of the figure. The greater part of the right lateral column is seen to have been spared from injury. Three weeks subsequent to this second lesion the animal was sacrificed. Preparations made with the Marchi method for revealing degenerate nerve fibres showed the degeneration indicated by diagrams 2, 3, 4 and 5 in the figure. After the second injury to the cord the scratch-reflex remained elicitable from the right shoulder, but was lost from the left shoulder in its anterior scapular region. The degeneration of these proprio-spinal fibres descending from the shoulder segments went, therefore, hand in hand with disappearance of the scratch-reflex from a region of skin of the shoulder whence it was elicitable previously. (Sherrington.)

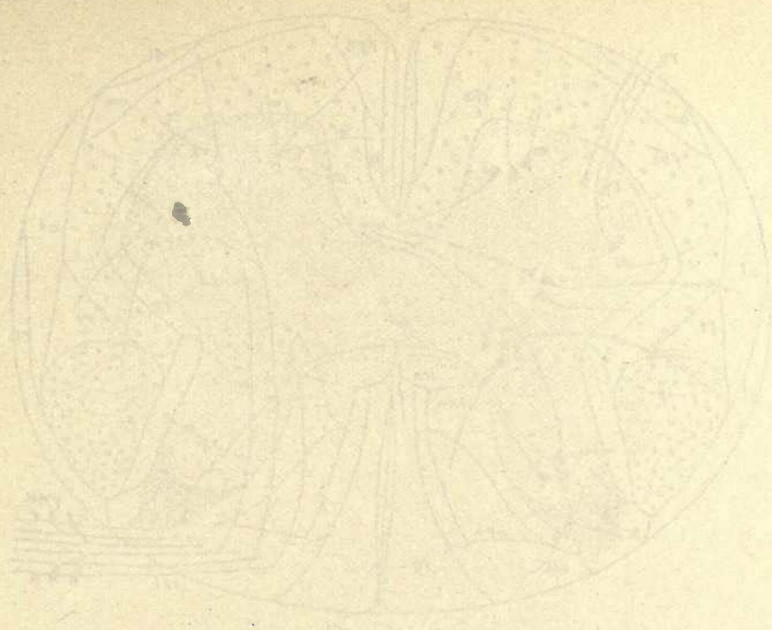

Fig. 60.—Diagram representing the [illegible] of [illegible] of the [illegible] the [illegible] to the gray matter [illegible] of the spinal cord.

The [illegible] of the cells of the gray matter and the [illegible] of nerve fibres of the white substance of the spinal cord.

1. THE ROOTS.

a, the cells [illegible] of the anterior nerve roots; ae, external trunk; ai, internal trunk of a root [illegible] with [illegible] cells going to a [illegible] external group of cells of the anterior horn [illegible] to a group [illegible] the latter, [illegible] posterior horn [illegible] to the column of Clark.

2. THE GRAY MATTER.

a, cells of the lateral column; b, cells of the posterior column; c, cells, the [illegible] of which cross the white commissure [illegible] anterior commissure; d, the [illegible] of Clarke's cells of [illegible]; f, cells, the [illegible] of which cross the posterior commissure and go to the posterior horn of the opposite side; g, cells the [illegible] of which [illegible] into the posterior root zone.

3. [illegible] OF THE WHITE MATTER.

[illegible]

marginal root zone.

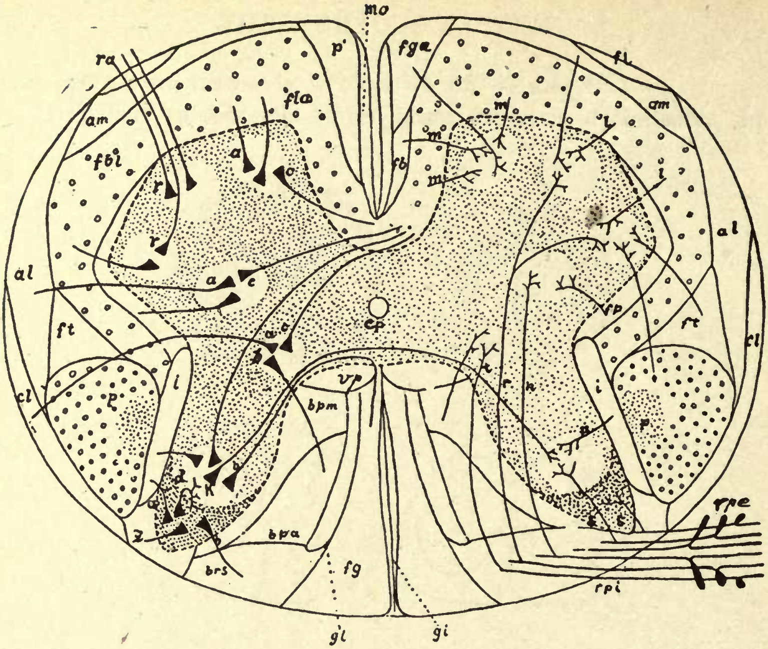

Fig. 66.—Diagram representing the manner of origin or termination of the roots of the spinal nerves in the gray matter substance of the spinal cord.

The distribution of the cells of the gray matter and the tracts of nerve fibres in the white substance of the spinal cords:

1. THE ROOTS

r, the cells; *ra,* the fibres of the anterior nerve roots; *rpe,* external trunk; *rpi,* internal trunk of a posterior nerve-root with, *n,* collaterals going to a posterior external group of cells of the anterior horn and, *r,* to a group anterior to the latter; *ss,* to posterior horn cells, and, *t,* to the column of Clark.

2. THE GRAY MATTER

a, cells of the lateral column; *b,* cells of the posterior column; *c,* cells, the axons of which cross the white commissure; *cp,* posterior commissure; *d* (in the substance of Rolando), cells of Golgi with short axons; *k,* cells, the axons of which cross the posterior commissure and go to the posterior horn of the opposite side; *r,* cells, the axons of which turn back into the posterior root zone.

3. COLUMNS OF THE WHITE MATTER

al, antero-lateral column or the column of Gowers; *am,* antero-marginal column or the column of Loewenthal; *bpa, bpm, brs,* median portion, antero and posterior columns of Burdach; *cl,* direct cerebellar tract; *fb,* continuation of the posterior longitudinal bundle; *fbl,* fibres of the lateral column; *fga,* fibres descending possibly from the anterior corpora quadrigemina, and passing across the base of the commissure; *fl,* fibres of the olivo-spinal tract; *fla,* fibres of the anterior columns; *fp,* fibres of the antero-internal column; *ft,* fibres of the prepyramidal tract of Monokaw; *gi,* portion of the column of Goll contiguous to the dorsal septums; *gl,* intermediate zone of the posterior column; *i,* fibres of the median or deep lateral column; *l,* fibres coming from the lateral column and terminating in the anterior horn; *m,* fibres from the anterior root zone; *n,* fibres from the deep column terminating in the posterior horn; *p,* lateral pyramidal tract containing two kinds of fibres; *p,* antero-pyramidal tract; *cp,* ventral zone of the posterior tract; *z,* external or marginal root zone.

2. Fibers to the cells of the posterior horn of the opposite side.

3. Fibers to the median group of cells of the anterior horn.
4. Fibers to the cells of Clarke's column.
5. Fibers to the anterior cells of the anterior horn.

—*Significance of the Termination of the Fibers of the Posterior Nerve Roots.*—Means, therefore, exist by which an incoming impulse may pass upward for the whole length of the spinal cord or downwards or upwards for several or many segments of the spinal cord or to a number of different groups of nerve cells within the gray matter.

2. *Intersegmental Fibers and Their Positions* (Fig. 65).—The fibers passing between different segments of the spinal cord are of much importance. Within the white matter of the spinal cord they occupy the following regions:

a. In the lateral columns immediately outside the central gray matter in the concavity formed by the two horns.
b. Close to the gray matter in the anterior basic bundle.
c. In the posterior columns the following three situations: (1) Close to the tip of the posterior horn. (2) A small area between the columns of Goll and Burdach—the comma tract. (3) Close to the posterior fissure—the septomarginal bundle.
d. Mingled with the fibers of the pyramidal tract.

CONDUCTING FUNCTIONS OF THE SPINAL CORD

The Spinal Tracts.—Functionally similar nerve fibers within the spinal cord are seldom isolated. Almost all run in bundles with other fibers serving the same functions. Practically all nerve fibers within the cord are connected by means of collateral fibers with nerve cells of more than one segment. These collateral fibers, unlike their parent fibers, which are medullated, have no medullary sheath. The simple axis cylinder lies embedded in a layer of myelin surrounded immediately by neuroglia.

The various bundles of the spinal cord may be divided into: (1) Proprio-spinal or intersegmental fibers, fibers connecting various levels of the spinal cord, some of which are ascending and others descending; (2) Ascending bundles. (3) Descending bundles.

2. Fibers to the cells of the posterior horn of the opposite side.

3. Fibers to the median group of cells of the anterior horn.

4. Fibers to the cells of Clark's column.

5. Fibers to the motor cells of the anterior horn.

Significance of the Distribution of the Fibers of the Posterior Nerve Roots — Means, therefore, exist by which an incoming impulse may pass upward for the whole length of the spinal or downwards or upwards for several or many segments of the spinal cord or to a number of different groups of nerve cells within the gray matter.

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CONDUCTING FUNCTIONS OF THE SPINAL CORD

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The various bundles of the spinal cord may be divided into: (1) Proprio-spinal or internuncial fibers, fibers connecting various levels of the spinal cord, some of which are ascending and others descending. (2) Ascending bundles. (3) Descending bundles.

Some of the proprio-spinal tracts have already been considered. Inasmuch as they are both ascending and descending we will describe them together with the ascending and descending tracts. (Figs. 61, 65 and 67.)

Descending Tracts — *Pyramidal Tracts* — Found immediately in front of the base of the posterior horns. It contains fibers which originate in the nerve cells of the motor area of the cerebral cortex and run without interruption through the cerebral peduncles, through the pons Varolii, and through the medulla, where they decussate with each other to gain the opposite side to enter the pyramidal tract of the spinal cord and terminate by a terminal arborization probably directly around the motor cells of the anterior horns of the cord. By collaterals they communicate with the cells of several levels.

The Prepyramidal Tract — Situated in the spinal cord immediately in front of the pyramidal tract. It begins in the red nucleus of the mid brain. The tract very probably represents an indirect cerebellar spinal tract, in other words it continues the efferent impulses from the cerebellum through the superior peduncles through the red nucleus to the spinal cord.

The Vestibulo-Spinal Tract — This tract establishes connections between the higher equilibrium centers and the spinal cord. It begins in the cells of Deiter's nucleus of the medulla, which is an important substation to the cerebellum. The fibers of the vestibulo-spinal tract are scattered in the antero-lateral column.

The Olivo-Spinal and Thalamo-Spinal — Situated opposite the tip of the anterior horn. It begins in the optic thalamus and in cells of the inferior olivary body. The latter may be regarded as a substation for many of the fibers between the thalamus and the cord.

Tract of Marie — A proprio-spinal tract, serving the same purpose as the posterior longitudinal bundle to be studied later in the brain. Its fibers are both ascending and descending and scattered in the anterior columns.

Comma Tract — In the interval between the columns of Burdach and Goll, chiefly descending branches of the entering posterior spinal nerves.

Septo-marginal — Chiefly proprio-spinal, and situated adjacent to the posterior portion of the posterior fissure.

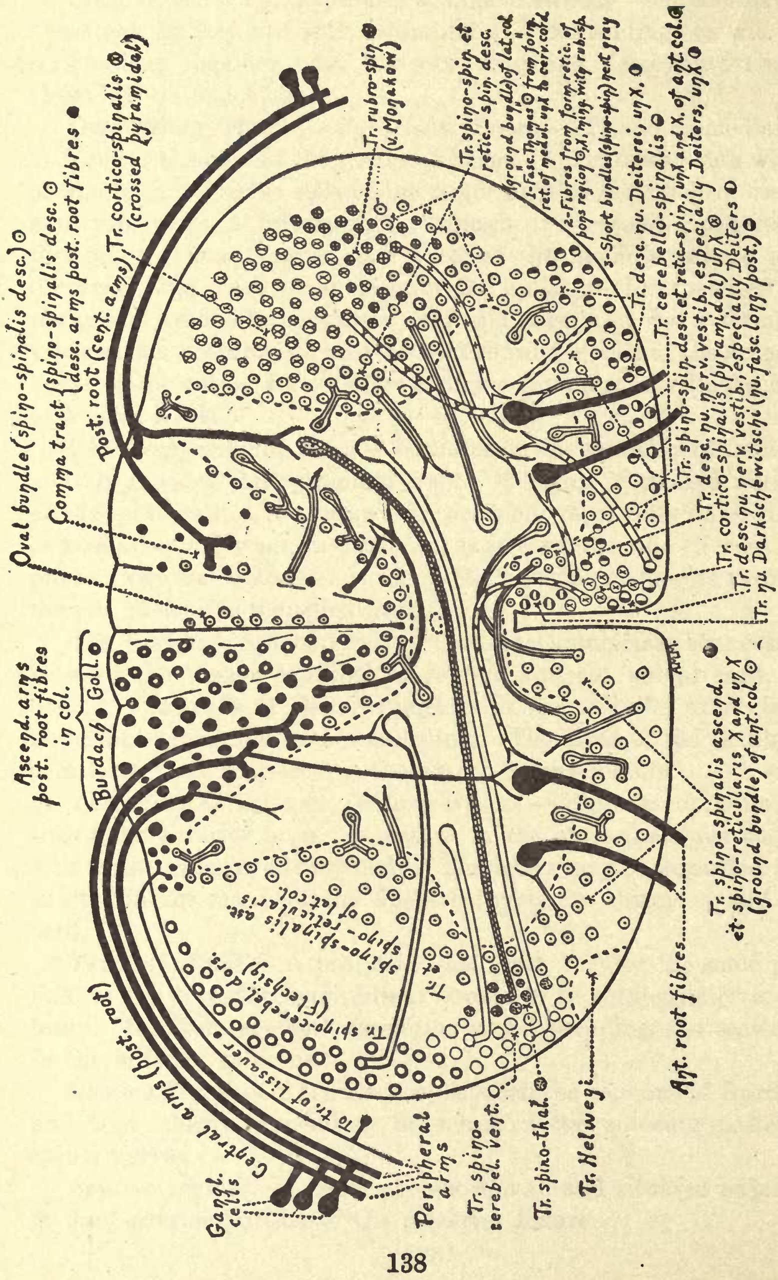
Oval bundle (spino-spinalis desc.)
Comma tract {spino-spinalis desc. / desc. arms post. root fibres
Post. root (cent. arms)
Tr. cortico-spinalis (crossed pyramidal)
Tr. rubro-spin. (v. Monakow)
Tr. spino-spin. et retic.–spin. desc.
ground bundle of lat. col.
1-Fasc. Thomas from form. ret. of medul. un X to cerv. cord
2-Fibres from form. retic. of pons region, X, ming. with rub-sp.
3-Short bundles (spino-spin) next gray
Tr. desc. nu. Deiteri, un X.
Tr. cerebello-spinalis
Tr. spino-spin. desc. et retic-spin., un X and X. of ant. col.
Tr. desc. nu. nerv. vestib., especially Deiters
Tr. cortico-spinalis (pyramidal) un X
Tr. desc. nu. nerv. vestib., especially Deiters, un X
Tr. nu. Darkschewitschi (nu. fasc. long. post.)
Ascend. arms post. root fibres in col.
Burdach
Goll.
Central arms (post. root)
To tr. of Lissauer
Tr. spino-cerebel. dors. (Flechsig)
spino-spinalis reticularis asc. of lat. col.
Gangl. cells
Peripheral arms
Tr. spino-cerebel. vent.
Tr. spino-thal.
Tr. Helwegi
Ant. root fibres
Tr. spino-spinalis ascend. et spino-reticularis X and un X (ground bundle) of ant. col.

Fig. 67.

Ascending Tracts — *Posterior Columns* — Divided into the *column of Burdach,* the postero-lateral, and the *column of Goll* or postero-median. The fibers of the posterior columns are derived from ascending divisions of the entering posterior nerve roots. As these enter they occupy first the postero-lateral column but become displaced internally by similar fibers entering at higher levels. Therefore the column of Burdach of the lumbar region becomes the column of Goll in the cervical region. In the cervical region the column of Goll contains fibers from the lower extremities and the column of Burdach the fibers from the upper extremity. They terminate in the medulla around cells of the nucleus cuneatus and nucleus gracilis.

The Direct or Dorsal Cerebellar Tract — Situated just anterior to the outer extremities of the posterior horns, external to the pyramidal tract. It may be viewed as one of the two afferent spino-cerebellar tracts. Its fibers originate as axons of the cells of Clark's column, and run up to the corpus restiforme, then entering the inferior cerebellar peduncle.

The Anterior or Ventral Cerebellar Tract — Situated anterior to the dorsal cerebellar tract, between it and the bundle of Helweg. It ascends through the medulla to join the superior cerebellar peduncle, by which it enters the cerebellum, to end in the cells of the ventral nuclei of the superior worm. Inasmuch as this tract does not increase in size, as it ascends, some of its fibers may join the dorso-cerebellar tract or end in the cord.

Spino-Thalamic — Situated just internally to the anterior cerebellar fibers, forming a tract which is often described as one tract with the anterior cerebellar tract—the tract of Gowers. It terminates in the cells of the anterior corpora quadrigemina, but chiefly in the cells of the optic thalamus.

Proprio-Spinal Fibers — Chiefly the ascending fibers of the tract of Marie in the antero-lateral column.

Functions of the Various Tracts — Motor impulses descend through the pyramidal tracts, and the indirect or crossed pyramidal tracts, immediately lateral to the anterior fissure.

Impulses of pain both superficial and deep enter through the posterior roots, cross immediately to the other side of the cord and ascend in the internal portion of Gowers' tract to the optic thalamus. (Fig. 68.)

impulses of heat and cold follow the same course.

Impulses of touch and pressure cross, after running upwards for a few segments in the cord, to the other side of the cord and ascend to the optic thalamus in the antero-lateral column. Some of the fibres of cutaneous touch particularly those of tactile discrim-

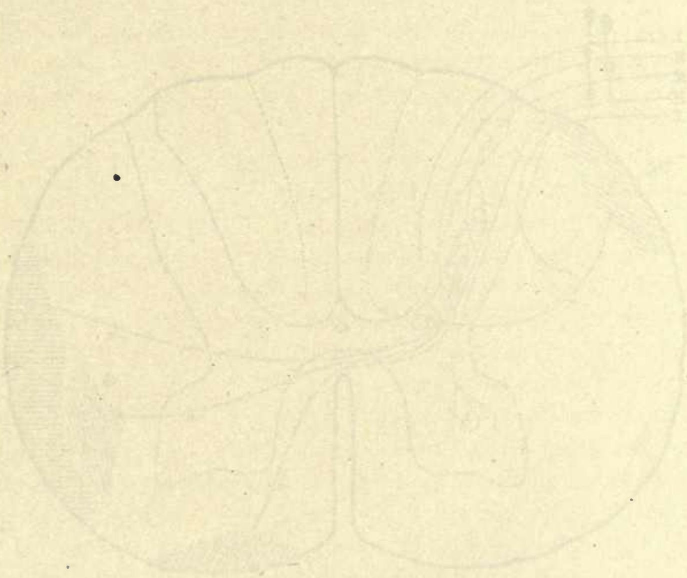

FIG. 63.—The sensory paths shown in passing the posterior root.
1, The fibres of the posterior columns.
2, Fibres entering connection with Clarke's column and afferent [illegible] cerebellar tract [illegible].
3, [illegible] and 5, fibres [illegible] connection with posterior horn cells and [illegible] in the anterior [illegible] [illegible] conveying [illegible] [illegible] impulses of muscle [illegible] and other [illegible]. [illegible] impulses of pain, heat and cold. 4 [illegible] [illegible] impulses of touch and [illegible]

ination travel upwards uncrossed in the posterior columns. Considerable evidence exists that touch impulses follow a different course than cold and heat temperature. We must regard sensibility [illegible] as compounded of superficial tactile discrimination and superficial pressure sensation. In the disease of syringomyelia, the senses of temperature and pain are affected while the sense of touch is not. Moreover unilateral section of the cord does

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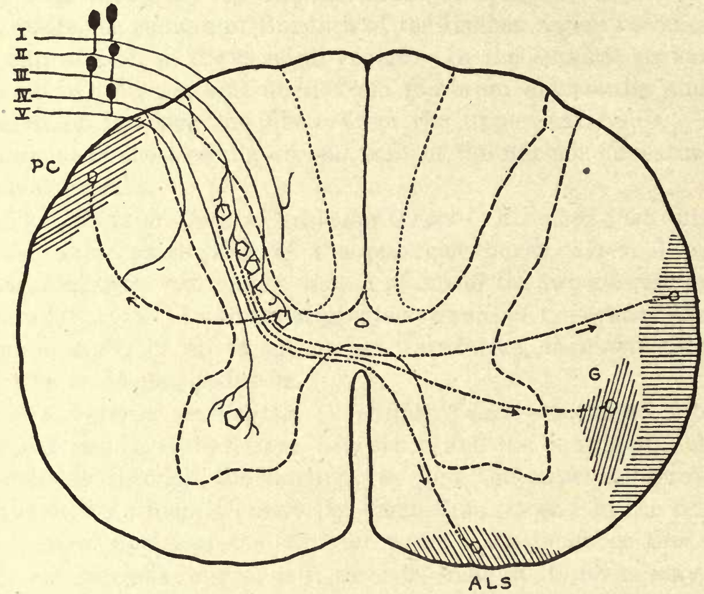


Fig. 68.—The course of the fibres composing the posterior root.

I. The fibres of the posterior columns.

II. Fibres making connection with Clark's column and continued upward in the posterior cerebellar tract, *P. C.*

III, IV, and V. Fibres forming connection with posterior horn cells and continued upward in the anterior cerebellar tract, *AC,* conveying heterolateral unconscious afferent impulses of muscular coördination and reflex tone. *G.,* Gowers' column transmitting impulses of pain, heat and cold. *A. L. S.,* Antero-lateral ascending sensory tract conveying impulses of touch and pressure.

ination travel upwards uncrossed in the posterior columns. Considerable evidence exists that touch impulses occupy a different course than pain and temperature. We must regard superficial touch sensations as compounded of superficial tactile discrimination and superficial pressure sensation. In the disease of syringomyelia, the senses of temperature and pain are affected while the sense of touch is not. Moreover unilateral section of the cord does

not completely abolish the sense of touch on the same side below the level of the lesion.

Impulses of muscular sensibility may be divided into those which reach consciousness and those which do not. The former are all homolateral within the spinal cord and make up the posterior columns. The latter are partly homolateral, forming the direct or posterior cerebellar tract, and partly heterolateral, forming the anterior cerebellar tract.

Unilateral section of the Cord will produce the following symptoms:

Motor paralysis below the site of the lesion upon the same side.

Partial loss of consciousness of the position of the limbs below the site of the lesion on the same side.

Complete anesthesia below the level of the lesion on the opposite side. There will be a preservation of sensations of touch and pressure for four or five segments below the level of the lesion on the opposite side. There will be slight anesthesia for a narrow strip at the level of the lesion on the same side. This narrow zone will be above a hyperæsthetic zone.

There will be a paralysis of the vaso-motor nerves below the level of the lesion on the same side. Vasomotor impulses travel down the cord from the medulla on the same side.

SPINAL FUNCTIONS

For the study of the functions or reactions of the spinal cord a study of the cord separated from the brain furnishes much valuable information. We are then able to study what may be termed pure spinal reactions, reactions uninfluenced by impulses continually descending from above. An animal in which the spinal cord has been severed from the brain is called a spinal animal.

Spinal shock is the first effect of dividing the spinal cord. There is a great fall in the blood pressure and absolute paralysis of the skeletal muscles and of the sphincters and abolition of all reflexes.

The shock appears to only exist aboral to the plane of section. In monkeys, for instance, after section of the cord below the cervical region, though there is a fall of blood pressure and paralysis of the trunk and lower extremities, nevertheless all muscles supplied by nerves issuing from the cord above the plane of section

are active. Immediately after the section the animal will gaze out of the window in a contented manner and even catch at flies. After a period, which is proportional to the height in the scale of life which the animal occupies, recovery from the shock occurs. Permanent paralysis of voluntary motion and loss of sensation remains for all regions below the plane of section.

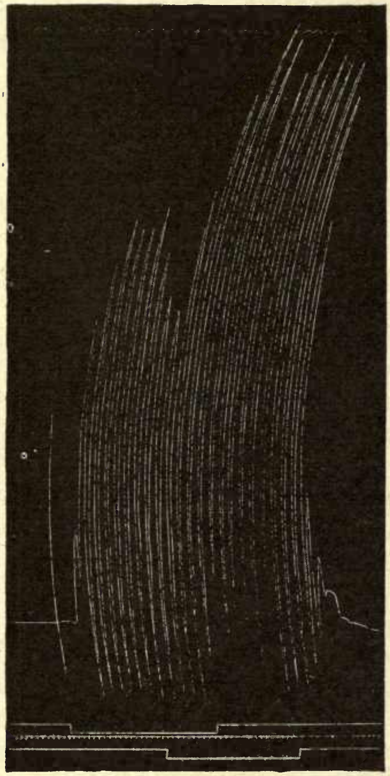


Fig. 69.—Tracing of the flexion of the hip in the "scratch-reflex."

The reflex is evoked by two separate stimulations (unipolar faradization) at points ten centimeters apart on the skin surface. The upper signal shows the time of application of the first stimulation, and the line immediately below that the frequency of repetition of the double induction shocks of that stimulation. The lowest line signals the time of application of the second stimulation; the frequency of repetition of the double shocks in this stimulation was much greater than in the other stimulation and is not shown. At the top the time is marked in fifths of seconds. The moment of commencement of the first stimulation is marked by an abscissa on the base line. The periods of the two separate stimulations overlap, the second beginning a full second before the first ends, but no interruption or increase of the rate of rhythmic reflex-response appears. (Sherrington.)

Recovery from the Shock — From the shock, however, the animal *recovers.* The blood pressure first rises to normal. The sphincters become functional and the bladder and rectum capable of emptying themselves. Finally muscular tone is regained and coördinated movements (reflexes) may be excited by stimuli. The first reflexes to reappear are those dependent upon painful or nocuous stimuli and later those reflexes depending upon stimulation of nerve endings in the joints and end organs in the muscles.

Cause of Spinal Shock — Spinal shock does not depend upon

the lowered blood pressure nor to the trauma of the operation. Regions not in the shock above the plane of section are exposed to the same lowered blood pressure and a second section below the first, even if performed with little precaution to avoid trauma,

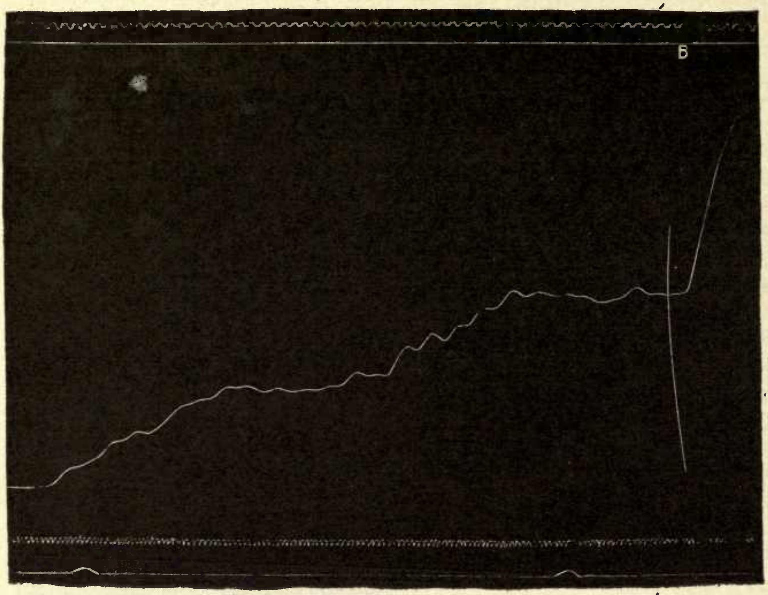
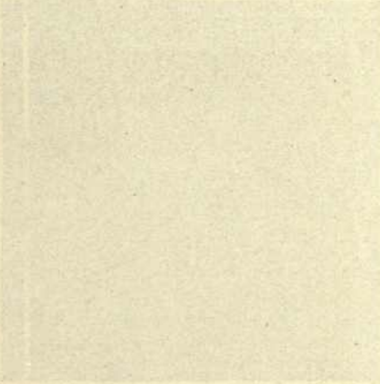


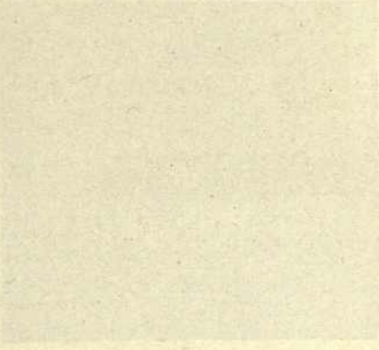
Fig. 70.—Flexion-reflex. Spinal dog. Latent time of incremental reflex compared with that of initial reflex. Unipolar faradization by break shocks. Kathode at needle-point in plantar skin of outermost digit.

A weak initial stimulus is delivered and maintained, and then when the resulting reflex movement has become steady the stimulus is increased in intensity by short-circuiting 5 ohms from the primary circuit. The rate and intensity of the break shocks are marked above by a recording electromagnet; the armature is arranged to have an ampler excursion when the current is increased at the point marked *B*. The latent time of the incremental reflex is seen to right hand, and is distinctly shorter than that of the initial reflex. Time below is written in 1/100 sec. and in seconds. Abscissæ on the myograph line show the moment of first delivery of the initial (*A*) and of the incremental (*B*) stimuli. (Sherrington.)

does not add to the degree of shock. It is directly dependent upon the cutting off of the normally descending impulses from higher parts of the nervous system which, so to speak, keep the cord awake and responsive.

Recovery from the shock depends upon the power of the spinal centers to acquire a more independent activity of their own in





the absence of the assistance of the central nervous system. In the dog recovery may even occur to such an extent that it may be able to take a few steps if it be raised and given a push, although it cannot walk.

Swimming movements may be carried out regularly. They are not voluntary but purely reflex, the necessary sensory stimulus being supplied by the extension of the muscles, and are of the nature of alternate flexion and extension in the hind limbs when the animal is held upright by his fore limbs.

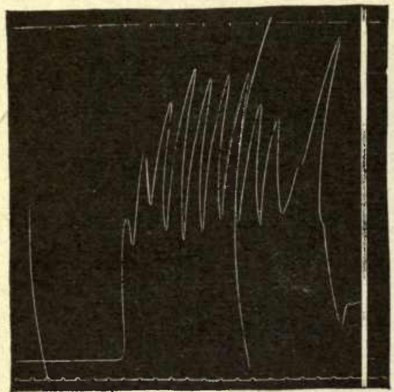
A Study of the Spinal Reflexes — *Scratch Reflex* — Continued gentle stimulation over the shoulders will cause rhythmic flexion and extension of the hind limb of the same side as though making an attempt to brush off the irritant. (Figs. 69–71.)

Sole Reflex — Pricking the sole of the foot will cause flexion of the leg and thigh and, if the stimulus is strong enough, extension of the opposite leg.

Gentle pressure upwards against the sole will cause extension of the same leg and flexion of the opposite leg.

Vascular Reflex — A rise in blood pressure may be obtained from afferent stimulation of the digital nerve. (Fig. 72.)

Bladder and rectal reflex is the stimulus within the bladder



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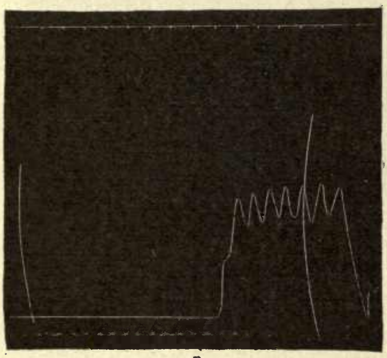


B

Fig. 71.—*A, B,* Scratch-reflex. The tracings show the usual lengthening of latency on reducing the intensity of the stimulation. The two tracings are in reproduction unequally reduced, but the frequency of repetition of the double-induction shocks used as stimuli was the same in both shocks of weaker intensity in *B* than in *A*. The reflex movement began after delivery of three stimuli in *A*, after delivery of nine in *B*. The greater intensity of the stimuli in *A* is also evidenced by the greater amplitude of the movement and by the longer "after-discharge." Time marked in fifths of seconds below.

and rectum of urine and feces which will cause voluntary evacuation of these organs. Even coitus and parturition may occur.

Muscular Tone.—The degree with which muscular tone can return is illustrated in a frog which has recovered from spinal shock by section of the posterior spinal nerves on one side. That side will then be perfectly flaccid and completely extended contrasting with a partially flexed position of the other leg when the animal is suspended. (Fig. 73.) In other words, after the recovery from the shock stimuli are continually ascending to the spinal cord from the muscles themselves which excite low afferent stimuli that keep the muscles in some degree of contraction. The partial contraction, in other words the keeping the muscles in a condition of slight tautness, is called tone.

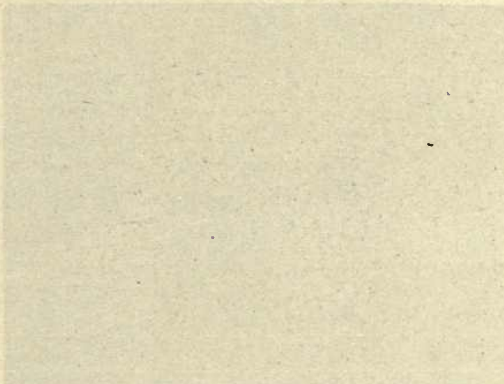


FIG. 73.—Spinal preparation reflex; dog, one hour after spinal transection at eighth cervical level. [illegible] and [illegible]. Isometric myogram [illegible] of severed end of a digital nerve [illegible] during the time marked by signal on second line from bottom. The [illegible] Time marked below in 2 seconds. (Sherrington.)

Tendon Reflexes.—The patella reflex is only one of various other tendon reflexes. Indeed the phenomenon is common to all tendons. It illustrates the factors determining muscular tone.

A tendon reflex may be elicited by tapping the tendon of a limb placed in a flexed condition but preferably in such a position that the tendon is somewhat on the stretch. For the right patellar reflex the right knee should cross the left allowing the leg to hang loosely over the left one. The patellar tendon is then sharply struck. Immediately the quadriceps extensor of the right limb will contract causing the leg to give a little jerk. The latent period between the time of the blow to the tendon and the contraction is very short according to Gotch only .03 of a second.

and rectum of urine and feces which will cause voluntary evacuation of these organs. Even coitus and parturition may occur.

Muscular Tone — The degree with which muscular tone can return is illustrated in a frog which has recovered from spinal shock by section of its posterior spinal nerves on one side. That side will then be perfectly flaccid and completely extended contrasting with a partially flexed position of the other leg when the animal is suspended. (Fig. 73.) In other words, after the recovery from the shock stimuli are continually ascending to the spinal cord from the muscles themselves which excite o t h e r efferent stimuli that keep the muscles in some degree of contraction. The partial contraction, in other words, the keeping the muscles in a condition of wakefulness, is called tone.

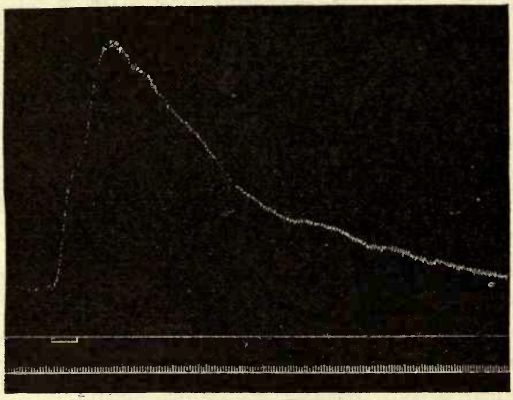


Fig. 72.—Spinal vasomotor reflex; dog; 300 days after spinal transection at eighth cervical level; chloroform and curare. Electrical stimulation of central end of a digital nerve of hind limb during the time marked by signal on second line from bottom. The arterial pressure (carotid) rises from 90 mm. Hg. to 208 mm. Hg. Time marked below in 2 seconds. (Sherrington.)

Tendon Reflexes — The patella reflex is only one of various other tendon reflexes, indeed the phenomenon is common to all tendons. It illustrates the factors determining muscular tone.

A tendon reflex may be elicited by tapping the tendon of a limb placed in a flexed condition but preferably in such a position that the tendon is somewhat on the stretch. For the right patellar reflex the right knee should cross the left allowing the leg to hang loosely over the left one. The patellar tendon is then sharply struck. Immediately the quadriceps extension of the right limb will contract, causing the leg to give a little jerk. The latent period between the time of the blow to the tendon and the contraction is very short, according to Gotch only .005 of a second,

which is also the duration of the latent period when the vastus internus is directly stimulated.

Manifestly, therefore, it must be considered possible that the cause of the knee jerk is the direct effect of the blow upon the muscle, but this cannot be all. Section of the posterior nerve roots of the third and fourth lumbar nerves will abolish the knee jerk, so also stretching the hamstring muscles or the antagonists of the flexors or weak stimulation of the nerve supplying hamstrings.

Fig. 73.—Illustrating the difference in the tone of the legs of a frog when the posterior root nerves of one side have been divided.

Section of the hamstrings or their nerve will increase the knee jerk reflex. These facts indicate that an afferent path to the spinal cord is necessary for the elicitation of the tendon phenomenon, and also a relaxation of the antagonists to the muscles which produce the contraction of the muscles which are concerned in the tendon reflex in question.

In order to accomplish this relaxation, a reflex arc through the spinal centers is necessary, a fact also attested by the abolition of the knee jerk in consequence of dividing the posterior spinal roots.

It has been suggested that the part played by the spinal cord is one merely maintaining muscular tone, keeping, so to speak, the muscles in a state of wakefulness. While this suggestion may in a large part explain the characters of the tendon reflex, it is not the entire explanation. More accurate measurements by Jolly of the current of action in the muscles and nerves, with a sensitive galvanometer, show in disagreement with the conclusions of Gotch that the latent period of the knee jerk contains also a small reduced reflex time of .002 of a second, corresponding perhaps with only one synapse. These measurements are as follows:

	[illegible]	Time of knee jerk
	[illegible]	Time of a sensory ending
	[illegible]	Time in nerve conduction
[illegible]	[illegible]	Time of motor endings
[illegible]		

Other examples of tendon reflexes are the Babinski sign and Kernig's sign.

These tests are all employed to obtain pathological conditions in man.

In locomotor ataxia, in which there is degeneration of the posterior columns of the spinal cord, including the mechanism for afferent impulses from the muscles, there is a loss of knee jerk. In the disease lateral sclerosis, in which the pyramidal tracts are degenerated, there is no longer exerted any controlling influence from above upon the motor mechanism of the cord and the motor mechanism of the cord, as in recovery from spinal shock, assumes an independent and exaggerated activity; consequently the knee jerks are increased.

SUMMARY OF THE PROPERTIES OF THE SPINAL CORD

The spinal cord may, therefore, be viewed as a part of a mechanism for obtaining a certain definite coordinated response of a limited segmental character from certain peripheral stimuli and for maintaining, as a result of certain deep seated stimuli, a muscular tone in the skeletal muscles. It also maintains a tone in certain of the vessels and structures within the body cavities conveniently though not accurately described as visceral tone.

The maintenance of both the skeletal tone and visceral tone is part of a reflex mechanism and is absent in the absence of the necessary afferent impulses or is changed with a change in the normal relation of excitatory or inhibitory impulses from above or from other parts of the nervous system.

The characteristics of a reflex response. *Purposive Idea.* — Every reflex movement may be described as a purpose-like movement for the simple reason that every reflex is an action frequently used by the animal. This fact constitutes the reason why during the process

Time of knee jerk		.0053
Time in afferent ending	.0004	
Time in nerve conduction	.0014	
Time in motor endings	.0013	.0031
		.002 +

Other examples of tendon reflexes are the Babinski sole reflex and Koernig's sign.

These facts are all confirmed by certain pathological conditions in man.

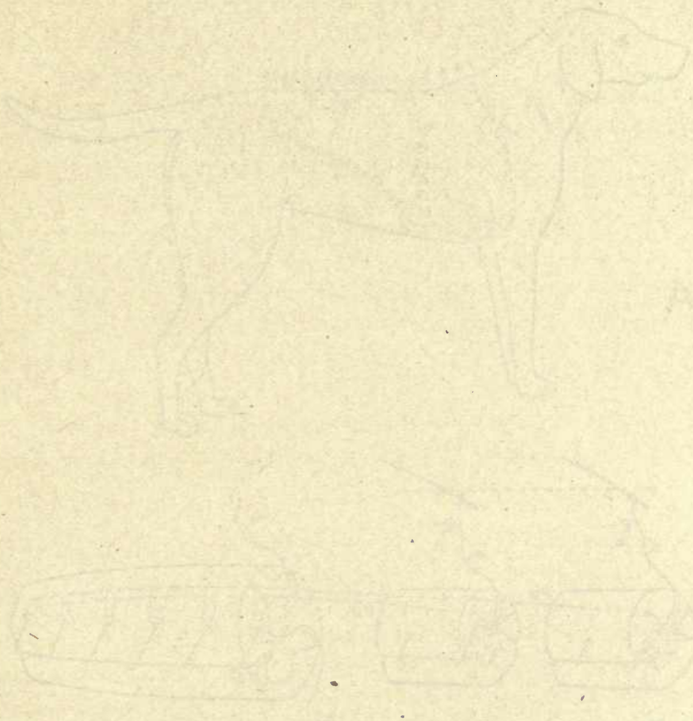
In locomotor ataxia, in which there is degeneration of the posterior columns of the spinal cord containing the mechanism for afferent impulses from the muscles, there is a loss of knee jerk. In the disease lateral sclerosis, in which the pyramidal tracts are degenerated, there no longer exists any controlling influence from above upon the motor mechanism of the cord and the motor mechanism of the cord, as in recovery from spinal shock, assumes an independent and exaggerated activity, consequently the knee jerks are increased.

SUMMARY OF THE FUNCTIONS OF THE SPINAL CORD

The spinal cord must, therefore, be viewed as a part of a mechanism for obtaining a certain definite coördinated response of a limited segmental character from certain peripheral stimuli and for maintaining, as a result of certain deep seated stimuli, a muscular tone in the skeletal muscles. It also maintains a tone in certain of the vessels and structures within the body cavities conveniently though not accurately described as visceral tone.

The maintenance of both the skeletal tone and visceral tone is part of a reflex mechanism and is absent in the absence of the necessary afferent impulses or is changed with a change in the normal relation of excitatory or inhibitory impulses from above or from other parts of the nervous system.

The Characteristics of a Spinal Reflex — *Purpose-like* — Every reflex movement may be described as a purpose-like movement for the simple reason that every reflex is an action frequently used by the animal. This fact constitutes the reason why during the process


A
B

of development the various neurons are so connected that the various reflexes become possible. The word *purpose-like* has been used instead of purposeful because every reflex act is at the same time *fateful.*

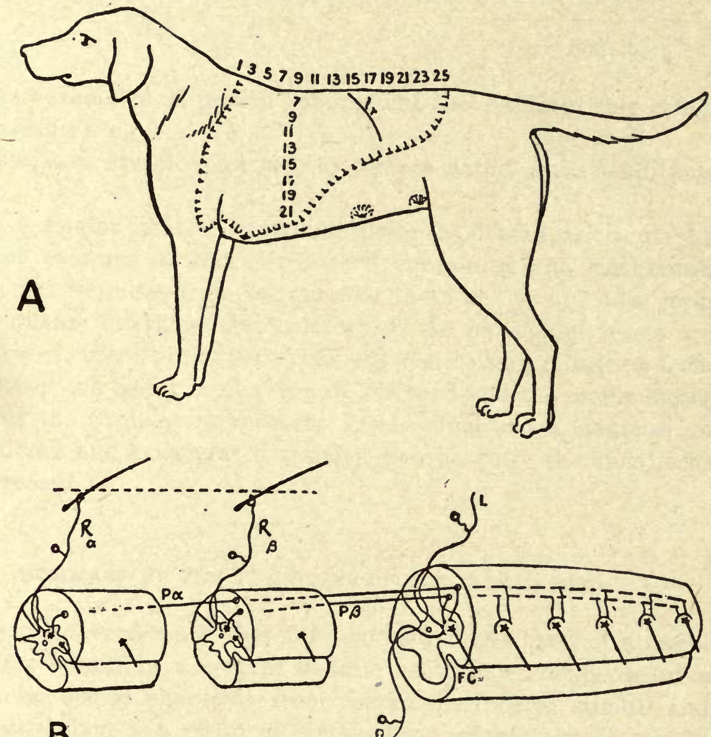
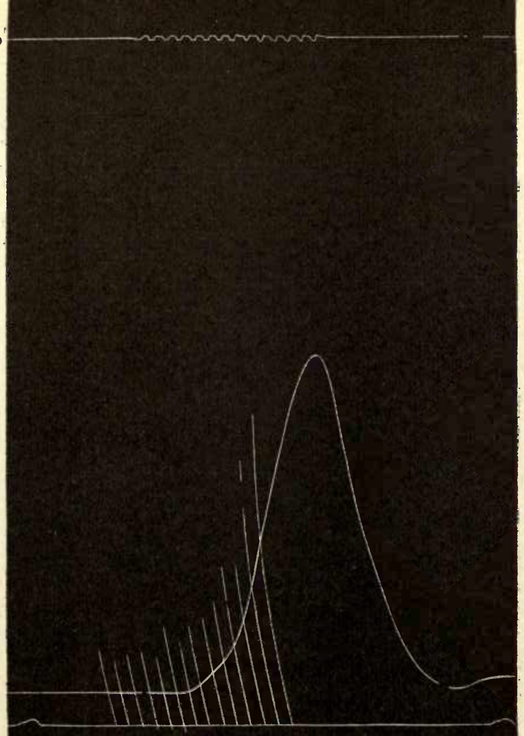


Fig. 74.—*A:* The "receptive field," as revealed after low cervical transection, a saddleshaped area of dorsal skin, whence the scratch-reflex of the left hind limb can be evoked. *lr* marks the position of the last rib.

B: Diagram of the spinal arcs involved. *L,* receptive or afferent nerve-path from the left foot; *R,* receptive nerve-path from the opposite foot; *Ra, Rb,* receptive nerve-paths from hairs in the dorsal skin of the left side; *FC,* the final common path, in this case the motor neurone to a flexor muscle of the hip; *Pa, Pb,* proprio-spinal neurones. (Sherrington.)

Fateful — The spinal cord, unless inhibited by actions of the higher nervous system, always responds in a definite calculable manner. The beheaded eel will wind itself around a red hot poker. The beheaded snake will spring back to any agent grasping its tail.



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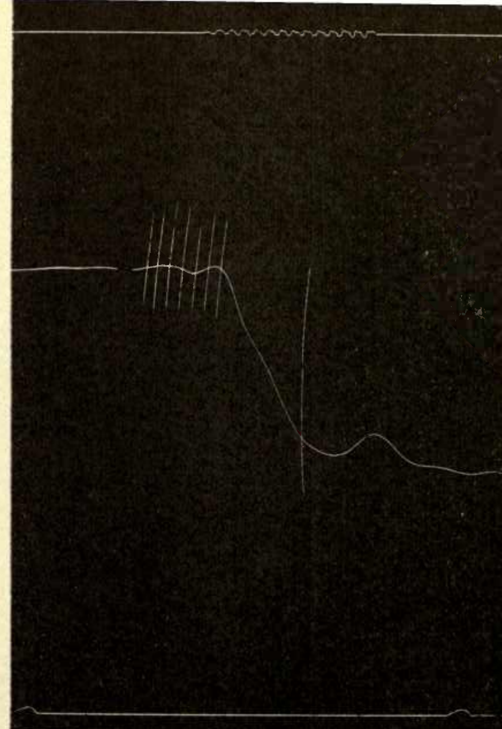


B

Fig. 74½, *A* and *B*.—The "Flexion-reflex" observed as reflex contraction (excitation) of the flexor muscle of the knee (Fig. *A*) and as reflex relaxation (inhibition of the extensor muscle of the knee (Fig. *B*).

The afferent nerve stimulated is a twig of the internal saphenous below knee. The stimulation is by a series of break induction currents, the number and frequency of which are shown by the electromagnet record of the breaks and makes of the constant current feeding the primary spiral of the inductorium through a rotating key. The distance of the secondary coil from the primary remained the same in the two observations (Figs. *A* and *B*). The observation of Fig. *A*, and about four minutes later. The moment of delivery of the individual stimuli is marked by the abscissæ on the myogram; in Fig. *A*, six were delivered before the reflex contraction set in; similarly in Fig. *B*, six were delivered before the reflex relaxation set in. The intensity of the stimulating shocks was feeble, hence the relatively long latent periods. Time recorded in hundredth seconds above, in seconds below. (Sherrington.)

Pleurisegmental — All reflex movements are such as would under usual conditions perform useful acts for the animal, and all are complicated, involving several segments of the spinal cord. They are all pleurisegmental (see Fig. 74).

Capable of Spreading — The plantar or sole reflex in the mammal not only involves the extremity on the side of the provoked sensory stimulus but may also involve the extremity of the other side.

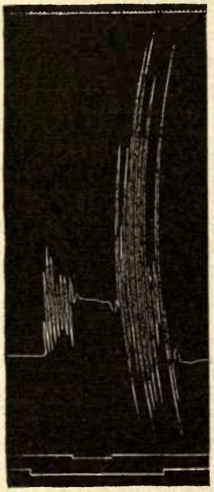
The *spreading* of the response is always in a definite order called *irradiation,* and just what response is called forth is determined by the place or *locus* of the peripheral stimulus. We have thus far only spoken of the contraction of certain sets of muscles in the description of this response, but the contracting muscles are only half of those which participate in the reflex act.

Capable of Inhibition — No reflex can effectively take place without the simultaneous relaxation of the set of muscles antagonistic to those which are undergoing contraction. During the reflex withdrawal of one foot (flexion) and extension of the opposite leg, there is not only contraction of the flexors but also relaxation of the extensors on the one side and contraction of the extensors and relaxation of the flexors on the other side. This relaxation is accomplished by impulses which inhibit centrally the impulses responsible for the normal muscular tone of the relaxing muscles. The relaxation may be measured by a recording instrument which demonstrates the actual lengthening of the muscle.

A reflex action may be altogether prevented by influences transpiring in other portions of the central nervous system. Any *inhibition* is accomplished by nerve fibers running to the central synapses of the reflex in question from the other portions of the nervous system. Certain reflexes are prepotent; others may be made prepotent by strong stimuli. Prepotent reflexes have a tendency to inhibit other reflexes which may be transpiring. The possibility of reinforcing the knee jerk reflex by pulling apart the clasped hands illustrates the presence, normally, of constant inhibitory impulses to the extensors of the thigh. If the reinforcing act precedes the stimulation of the reflex by .06 sec. the inhibition begins to appear.

Capable of Prepotency — Certain reflexes possess precedence over others. Reflexes from painful or nocuous stimuli will proceed

in the place of other reflexes which may have been started. Only one reflex can proceed at a time. The central nervous system only attends to one thing at a time. A reflex in process of performance will be checked by another reflex started by a stronger stimulus. The checking process is one of inhibition, but after the period of inhibition has passed the inhibited reflex will proceed again with renewed vigor, as though its stimulus during the period of inhibition were really effective though apparently only accumulatively so.



A

Fig. 75. — Scratch-reflex interrupted by a brief flexion-reflex.

The time of application of the stimulus evoking scratch-reflex is shown by the lowest signal line; that of the stimulus of the flexion-reflex in the signal line immediately above the other. Time marked in fifths of seconds at top of the record. The scratch-reflex returns with increased intensity after the interruption. (Sherrington.)

Capable of Reënforcement — If one reflex is proceeding, another reflex giving rise to an action coöperating toward the same end is started, will proceed and strengthen the first reflex. Strongly pulling the interlocked fists apart will reinforce the knee jerk.

Capable of Fatigue — Too frequent excitation of a reflex causes fatigue at the central synapse. If the stimulus exciting a reflex which has been fatigued is moved only a very slight distance to the side of the locus of the reflex, it will again proceed with renewed vigor. Therefore the most important site of the fatigue must lie in the synapse upon the afferent side of the reflex arc.

Explanation of the "Mark Time" Movement — Just as repetition of a reflex causes fatigue, so inhibition causes reënforcement of a reflex. These two facts explain the automatic swimming movement or the automatic and continuous flexion and extension of first one leg and then the other in the suspended dog. The weight of one leg produces a stimulus to the contraction of its flexors, accompanied by inhibition of flexion upon the opposite side. This flexion is followed by slight fatigue on the newly flexed side and a dropping of the inhibited side, which in turn is stimulated by this drop or extension and, in virtue of the rest during the previous period of inhibition, is

in a condition to respond to the stimulus produced by its own extension. This stimulus causes it to be flexed and the flexion in the first limb to be inhibited in its turn.

In the excitation and control of reflex actions two varieties of afferent impulses are concerned. One set of these impulses comes

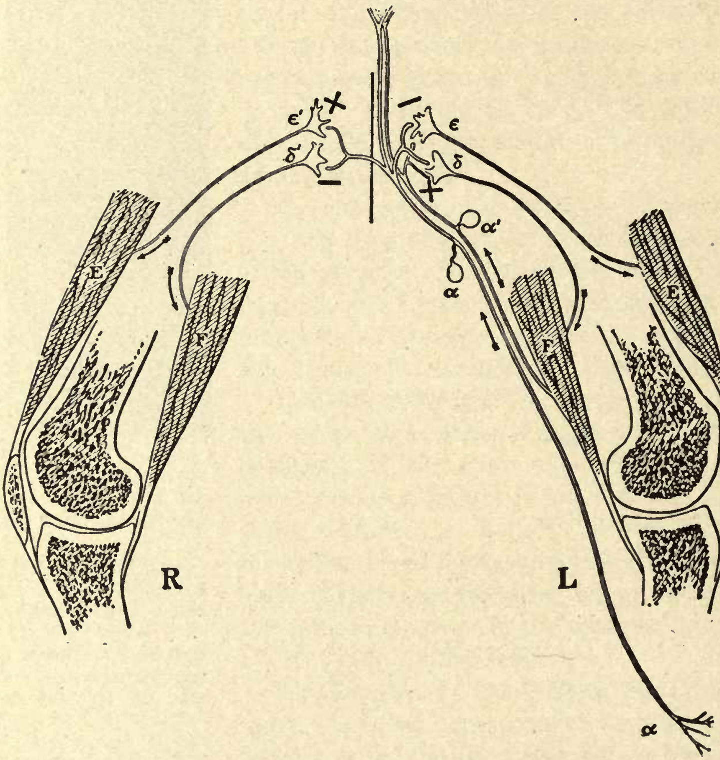


Fig. 75½.—Diagram indicating connections and actions of two efferent root-cells, *a* and *a′* in regard to their reflex influence on the extensor and flexor muscles of the two knees.

a, root-cell afferent from skin below knee; *a′*, root-cell afferent from flexor muscle of knee, i.e., in hamstring nerve; *e* and *e′*, efferent neurones to the extensor muscles of the knee, left and right; *s* and *s′*, efferent neurones to the flexor muscles; *E* and *E′*, extensor muscles; *F* and *F′*, flexor muscles. The "schalt-zellen" (v. Monakow) probably between the afferent and efferent root-cells are for simplicity omitted. The sign + indicates that at the synapse which it marks the afferent fibre *a* (and *a′*) excites the motor neurone to discharging activity, whereas the sign — indicates that at the synapse which it marks the afferent fibre *a* (and *a′*) inhibits the discharging activity of the motor neurones. The effect of strychnine and of tetanus toxin is to convert the minus sign into plus sign. (Sherrington.)

from the surface and may be termed *exogenous afferent impulses.* The second set originate within the muscles themselves and within the tendons and joints. They are the deep or *endogenous impulses.*

The first set are chiefly concerned in the excitation of reflexes. The second set chiefly, though by no means exclusively, with the degree with which the response to any particular reflex takes place in the various muscles concerned.

In other words the second set of impulses guide or control the response in such a manner that it is possible for it to become a coördinated movement. It is through them that information is obtained as to the degree of contraction of any muscle.

When these impulses are cut off the position of the limbs becomes abnormal. It is due to this fact that after the posterior nerve roots of one hind limb of a frog have been divided the frog's limb assumes a position of permanent extension and will hang with the legs limp.

If all the posterior nerve roots of the cervical nerves of one side, except the eighth, of a monkey are divided the monkey will still use its arm for climbing, but the movements will be inexact. The inexactness is chiefly in the arm. The hand, which is supplied by the eighth cervical, exercises perfect precision. The monkey has lost information from the muscles enabling it to know the various degrees of contraction of the muscles of the arm. If the eighth cervical nerve is then also divided, the arm will become totally paralyzed.

Capable of Localization — With the same certainty that a definite muscle contracts after the application of a stimulus to its motor nerve, so the application of a stimulus to the peripheral termination of a sensory nerve will call forth, in the absence of inhibitory influences, a definite response. A fixed path of least resistance for the propagation of the impulse to and through and from the central nervous system has been developed.

Capable of Delay — No response to a stimulus of a sensory neuron is immediate. A delay exists which represents the time necessary for the impulse to ascend the sensory neuron and for the impulse to pass across the synapse in the central nervous system and for the terminally provoked impulse, the efferent impulse, to descend the motor or secretory nerve.

The speed of impulse along nerve fibers is known and the latent

period involved in the starting of the sensory impulse and in the production of the effect by the efferent impulse, after the latter has reached the peripheral termination of the efferent nerve, are also known. When the time taken by these processes, which represents all the time of that portion of a reflex occurring outside the central nervous system, is subtracted from the total time of the simplest unilateral reflex act, there will be left over .008 of a second.

This time, therefore, represents the time of that portion of a reflex act which is occupied in the passage of its impulse across the synapses in the central nervous system. It is called the reduced reflex time. When the reflex is a crossed reflex the reduced reflex time is .004 of a second longer. Probably two additional synapses are involved in a crossed reflex, so that the time occupied in a single synapse is about .002 of a second.

Capable of Summation — To produce a reflex response by a single stimulus that stimulus must possess a certain strength. A weaker stimulus is a subminimal stimulus. A subminimal stimulus, however, is not necessarily without effect, inasmuch as several, five or six, subminimal stimuli applied at a proper interval will result in a response. The term summation is applied to this phenomenon.

Capable of Block — Fatigue illustrates one form of block, namely, an increased resistance across a synapse. The existence of a definite path for each reflex through the central nervous system demonstrates the presence of increased resistance to that reflex in all other synapses of the central nervous system. The reality of this increased resistance is made more evident when it is dissipated by the administration of strychnine or the tetanus toxine.

Capable of Facilitation — Some resistance to the passage of an impulse across the central synapse of a reflex exists even in that synapse which belongs peculiarly to the reflex in question. This resistance can be measured by the strength of current necessary to provoke the reflex. It may be diminished by frequently provoking the reflex at an interval not short enough to result in fatigue. This diminution of resistance across a synapse by use is called *facilitation.* Upon it depends the possibility of education and memory.

The Nature of the Path Across a Synapse — The transmission

of impulses so constantly in definite paths suggests the existence of a direct connection across the synapse. Certain observers have found good evidence of such direct connections among some of the lower orders of invertebrates and have maintained that they exist also throughout the nervous systems of animals. By special staining methods they have attempted to demonstrate actual connections between the dendrites of a nerve cell at nodal points in the terminal arborization of the afferent nerve fiber to this cell. In fact, some preparations show that the terminal arborization around a central nerve cell forms an actual basket of a netlike structure closely surrounding the cell with enlarged nodal points. Do the fibrillæ of the nerve cell run out into the dendrites and connect by means of them with these nodal points? The indirectness of such a path through a synapse may account for certain phenomena, such as delay existing at a synapse, but the law of forward direction will ever constitute an objection to the existence of a direct connection across a synapse.

There must exist a free ending to the dendrites of one neuron, and a beginning to the dendrites of the neuron next in the chain, and an interval filled with a different substance between the two.

Functions of the Various Portions of a Reflex Arc — The function of the nerve fiber is solely one of conduction. We may exclude excitation.

The function served by the synapse is also one of conduction.

What, however, is the function of the central nerve cell? May it originate impulses, or does it modify them, or does it solely conduct them, and are there any other possible functions which it may perform?

The Function of the Central Nerve Cell — In answering this question all the vital phenomena presented by living cells must be considered. Foremost among these is the maintenance of nutrition. We have seen that no cell is capable of continued existence without a nucleus. The sole purpose for which the nervous system has developed is one of communication. This is accomplished by nerve fibers. Each nerve fiber which, in many instances, constitutes the major part of the neuron, would be without a nucleus were it not for its attachment at one end to the nerve cell.

Trophic—In fact, the nerve fiber may be viewed as a long and permanent pseudopod of a nerve cell, and without attachment to

the cell will degenerate. An important function, therefore, of the nerve cell is the nutrition of its nerve fiber. The adjective *trophic* is the term which is used to describe this function.

Transmission — Nerve cells must transmit impulses. Less certainty, however, attaches itself to the question whether nerve cells modify impulses passing through them apart from other influences reaching them or even whether they may be spoken of apart from the fact that they are situated at a synapse as switch stations of the nerve impulses.

Automaticity — Much evidence exists that nerve cells do not originate nerve impulses. In the absence of all afferent stimuli they become functionless. Metabolic activity with the evolution of energy transpires within them. The evidence of this is supplied by the rapid loss of power to functionate in the absence of oxygen.

Clamping the aorta soon produces a paralysis of the whole spinal cord. Nevertheless, in the same manner a lack of oxygen will render nerve fibers incapable of conduction.

In some of the lower invertebrates the ganglion cells of afferent fibers may be excised without injury to the terminal arborization of the afferent and efferent nerve fibers to these cells and without immediately influencing in any way the function of the concerned neurons. So far, therefore, as the nervous activity of these cells is concerned it is limited entirely to transmission and trophic functions. Like other cells in the body the nerve cells have become highly differentiated for the purpose of performing most effectively one function.

This function is primarily one of reaction, a reaction which includes two factors, excitability and conductivity. It is very doubtful whether nerve cells possess any automatic function whatsoever. Even after large doses of strychnine have been administered in the absence of all afferent impulses, a condition, for instance, which exists after the section of all the posterior nerve roots, a frog will lie absolutely motionless.

Such serious changes in respiration are induced after cutting off all afferent impulses that it is possible that the demarcation currents, due to the trauma of the cut nerves may account for the incomplete and deficient respiration remaining after such an experiment.

TROPHIC FUNCTIONS OF THE CORD

We have thus far considered only the motor and sensory functions of the spinal cord. The spinal cord also exercises trophic functions upon both the muscles and the skin. When its connections with the muscles are severed, the muscles concerned atrophy. When the skin is separated by division of the posterior nerve roots it also shows nutritional changes. The skin becomes scaly, glossy, and the hair and nails show changes. When certain sensory nerves become inflamed peculiar eruptions appear. One very characteristic one is known in popular language as "shingles." The paths exerting trophic functions only become active in post-fetal life. During intrauterine life, even in complete absence of the nervous system, the muscles develop normally.

THE BRAIN

The Three Primary Cerebral Vesicles.

III

THE BRAIN

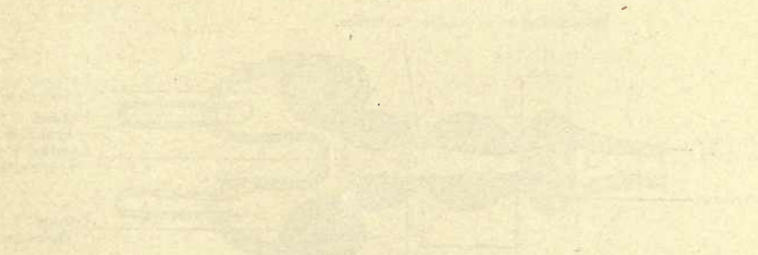
Development of the Brain — *Phylogenetically* the brain is changed anterior segments of the cerebrospinal axis having developed by alterations of nervous tissue similar in every way to the separate segments of which the spinal cord in mammals is composed and of which the more definitely segmental nervous system of the lower animals is formed. The alterations are due to the addition of new nerve tracts and new nerve centers.

The new nerve tracts connect the different portions of the brain and the brain with the different segments of the spinal cord. The new nerve centers serve as relay stations to the tracts connected with them, making possible a modification of the afferent impulses reaching them, by passing them on as efferent impulses — altered as to their destination or strength by a partial switching or by other impulses also reaching these centers from other portions of the nervous system — upon other afferent tracts to these same centers.

The Three Primary Cerebral Vesicles — After the primary neural groove has been transformed into a tube at the head end, *three cavities* become constricted off in such a manner as to partially separate them. These three cavities are the three primary cerebral vesicles, and it is from them that the three main divisions of the adult brain develop.

From the anterior vesicle develops the forebrain or the *prosencephalon.* It may be divided into the *thalamencephalon,* including the subsequent cerebral hemispheres, the lateral ventricles, the retina and the olfactory lobes, and the *diencephalon* which includes the third ventricle and the optic thalami. (Figs. 76–77.)

From the middle cerebral vesicle, or the mesencephalon, develops the corpora quadrigemina and the iter of Sylvius. *From the hindbrain,* the *rhombencephalon,* develops the cerebellum, the pons and the upper half of the fourth ventricle, together constituting a sub-



division known as the *myelencephalon,* and the lower half of the fourth ventricle known as the *metencephalon.*

The *retina of the eye* is developed from two lateral, stalk-like protrusions from the sides of the primary anterior cerebral vesicle.

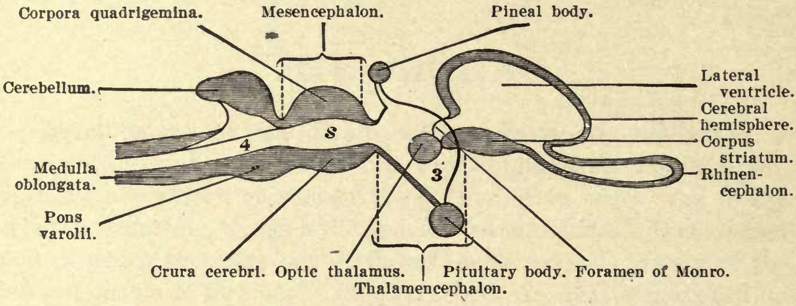


Fig. 76.—Diagrammatic sagittal section of a vertebrate brain. (Morris.) 4, fourth ventricle; *s,* cerebral aqueduct; 3, third ventricle.

Each *cerebral hemisphere* also develops by a bud-like expansion of the anterior extremity of the anterior cerebral vesicle. The bud contains a cavity which permanently retains its connection with the original cavity of the anterior cerebral vesicle. The growth of these

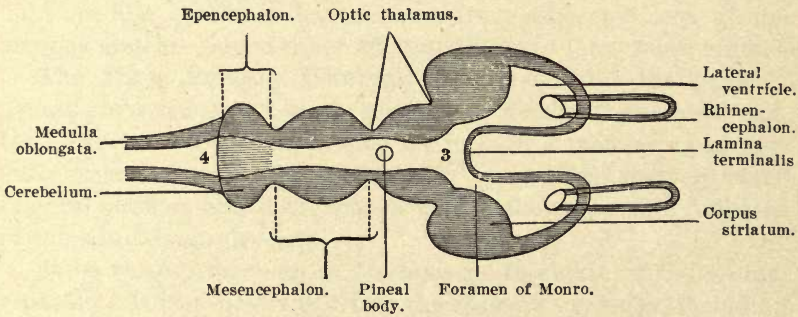


Fig. 77.—Diagrammatic horizontal section of a vertebrate brain. (Morris.) 4, fourth ventricle; 3, third ventricle.

buds is so excessive that they completely cover the sides and dorsum of the rest of the brain.

The original cavity of the buds becomes the lateral ventricle and its permanent connection with the cavity of the anterior cerebral vesicle constitutes what afterwards becomes the *foramen of Monro.*

A consideration of a [illegible] of the primary cerebral [illegible] and the adult brain will make these [illegible], and will clearly establish the relative positions of the various portions of the adult brain.

[illegible] at the junction between the spinal cord and the brain and passing from below upwards, the central canal of the spinal cord opens out [illegible] of the brain. The [illegible] portion the latter measures nearly two inches in length and about three-quarters of an inch in breadth at its widest portion. Posterior to the medulla and forming a large portion of the roof of the fourth ventricle is the cerebellum.

The [illegible] of the fourth [illegible]. It measures about [illegible] and a half. The most prominent structures forming the lateral boundaries of the fourth ventricle are the superior, middle and inferior peduncles of the cerebellum. These are thick bundles of white fibers by which the cerebellum is connected with the cerebrum, the pons, the medulla and the spinal cord respectively.

The Fourth Ventricle.—The floor of the fourth ventricle consists of gray matter, which, in this portion of the brain, represents the gray matter of the spinal cord uncovered posteriorly by the opening of the central canal of the latter.

It is diamond-shaped and divided at its middle by transversely running strands of nerve fibers, the [illegible], into an upper pontile and a lower bulbar portion. On the floor of the bulbar portion is a triangular depression [illegible] triangular [illegible], the [illegible]. From a [illegible] the [illegible]. (Fig. 15.)

The nucleus of the [illegible] the gray matter of the [illegible] of the eighth nerve, [illegible] the position of the more deeply placed [illegible] nucleus, [illegible] into the floor of the pontile portion of the fourth ventricle. [illegible] represented by a shallow depression [illegible] medially placed elongated [illegible], the eminentia teres. The eminentia teres is formed by [illegible] the nucleus of the sixth nerve. It corresponds in position above [illegible] to the trigonum hypoglossi below, and its [illegible] is the lowest [illegible] of the gray matter of the latter.

A comparison of a schematic representation of the primary cerebral vesicles and the adult brain will make these facts evident, and will clearly establish the relative positions of the various portions of the adult brain.

Beginning at the transition between the spinal cord and the brain and passing from below upwards, the central canal of the spinal column opens out into the *fourth ventricle* of the brain. Including its pontine portion the latter measures nearly two inches in length and about three-quarters of an inch in breadth at its widest portion. Posterior to the medulla and forming a large portion of the roof of the fourth ventricle is the *cerebellum.*

The cerebellum forms a large and separate division of the human brain. It measures about four inches by two by one and a half. The most prominent structures forming the *lateral boundaries* of the fourth ventricle are the superior, middle and inferior peduncles of the cerebellum. These are thick bundles of nerve fibers by which the cerebellum is connected with the mid-brain, the medulla and the spinal cord respectively.

The Fourth Ventricle — *The floor* of the fourth ventricle consists of gray matter, which, in this portion of the brain, represents the gray matter of the spinal cord displaced posteriorly by the opening of the central canal of the latter.

It is diamond-shaped and divided at its middle by transversely running strands of nerve fibers, the *striæ acusticæ,* into an upper pontine and a lower bulbar portion. On the floor of the bulbar portion is a triangular depression, the *ala cinerea,* separating a lateral triangular prominence, the *tuberculum acusticum,* from a median prominence, the *trigonum hypoglossi.* (Fig. 78.)

The nucleus of the pneumogastric nerve forms the gray matter of the ala cinerea. External to it is the nucleus of the eighth nerve. It overlies the position of the more deeply placed Deiters' nucleus, and extends up under the striæ acusticæ into the floor of the pontine portion of the fourth ventricle. In this region it is separated by a shallow depression from a more medially placed elongated prominence, the *eminentia teres.* The eminentia teres is formed by the gray matter of the nucleus of the sixth nerve. It corresponds in its position above the striæ acusticæ to the trigonum hypoglossi below, and its gray matter is the direct continuation of the gray matter of the latter.

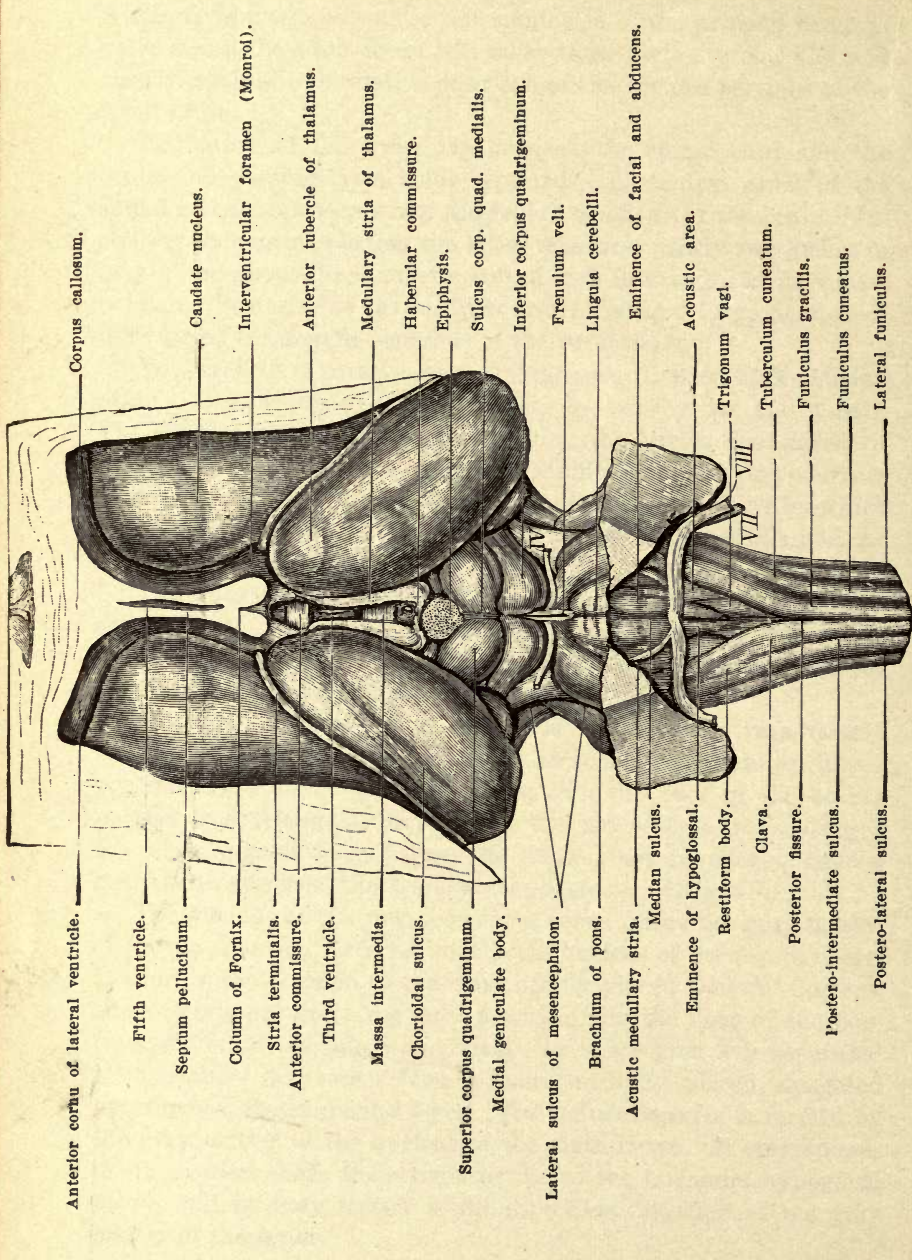


Fig. 78.—Dorsal surface of diencephalon with adjacent structures. (Morris.)

The [illegible] of Sylvius [illegible] upwards in the [illegible] [illegible] the [illegible] [illegible] [illegible] the central canal of [illegible] [illegible]. The gray matter [illegible]

[illegible] the middle line, [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

The Iter of Sylvius — Passing further upwards in the examination of the brain, the cavity of the fourth ventricle becomes again contracted into a narrow canal, *the iter of Sylvius* or the Sylvian aqueduct, which runs between it and the third ventricle. It is rather more than half an inch long. Like the central canal of the spinal cord it is surrounded by gray matter. The gray matter of its floor gives rise to the fourth and third nerves.

Four large nuclei, two upon each side of the middle line, cover its roof. These are called the *superior and inferior corpora quadrigemina.* Each forms a prominent rounded eminence upon the roof of the Sylvian aqueduct. The superior is intimately related with a smaller cylindrical eminence passing in an external direction from it. It is called the *external geniculate body* and receives, together with the superior corpora quadrigemina, a large number of the fibers of the optic nerve. A similar cylindrical eminence passes outward from the *inferior corpora quadrigemina.* It is called the *internal geniculate body,* and receives with the inferior corpora quadrigemina fibers from tracts originating in connection with the nucleus of the auditory nerve, situated below the medulla.

The Third Ventricle — At its upper extremity the iter of Sylvius enters the third ventricle. This is a narrow, cleft-like cavity, contained between two large nuclei of gray matter called the *optic thalami.*

The optic thalami form the most important and last subrelay station for many tracts between the cerebrum and lower portions of the brain or spinal cord.

The third ventricle is roofed in by the concave lower surface of the *corpus callosum,* a large mass of nerve fibers which collected in an elongated, flattened bundle connects the two cerebral hemispheres. It is curved in such a manner to be convex above and concave below.

The floor of the third ventricle is formed of the following structures beginning at the front: The anterior *perforated space,* a flat plane of gray matter which, with the *infundibulum,* forms a funnel-like cavity, leading down to the stalk of the pituitary gland, a pea-sized structure situated below and between the two.

Behind the infundibulum is another flattened plane, the *tuber cinereum.* More posterior are two knob-like structures, one on each

side of the middle line, called the *corpora mammillaria* or *corpora albicans.*

Between these and the anterior opening of the Sylvian aque-

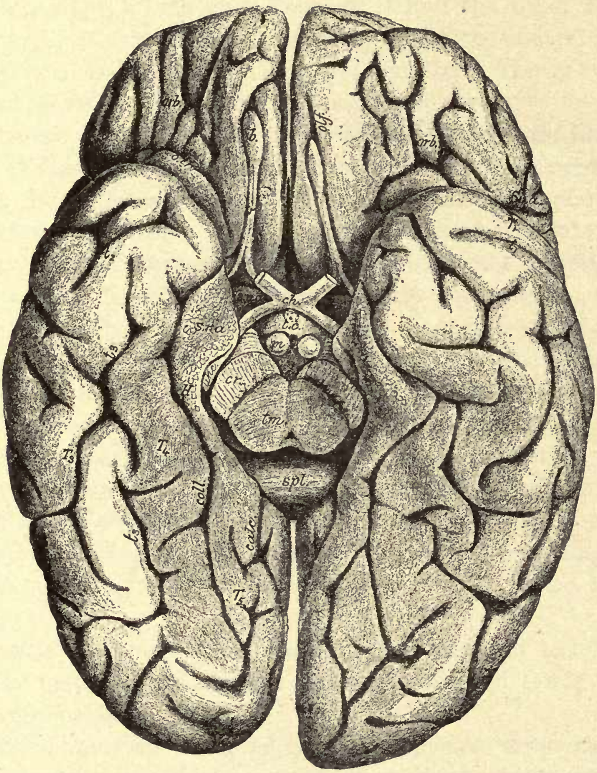


Fig. 79.—Under-surface of a simply convoluted European brain. (Quain.)
Sulci—*orb.,* orbital (sagittal rami); *o. tr.,* transverse orbital; *olf.,* olfactory; t_1, t_2, t_3, first, second, and third temporal; *coll.,* collateral (fourth temporal); *calc.,* calcarine.
Gyri—*R,* gyrus rectus; T_1, T_3, T_4, T_5, first, third, fourth, and fifth temporal; *H,* hippocampal; *s. r. a.,* caput gyri hippocampi; *unc.,* uncus.
ch., chiasma; *s. p. a.,* substantia perforata antica; *t. c.,* tuber cinereum; *m,* corpora mammillaria, accidentally separated from one another in the preparation; *cr.,* crusta; *tm,* tegmentum; *spl.,* splenium of callosum.

duct, or iter of Sylvius, is another inclined, flattened plane of gray matter, the *posterior perforated space.* Immediately above the anterior opening of the iter of Sylvius is the *posterior commissure,* consisting of a band of white fibers running across the two sides of

the brain in the formation and maintenance of consciousness [illegible] the point of termination of the visual tracts. The corpora [illegible] in close relation to the [illegible] quadrigemina.

The commissures. At the two sides of the [illegible]

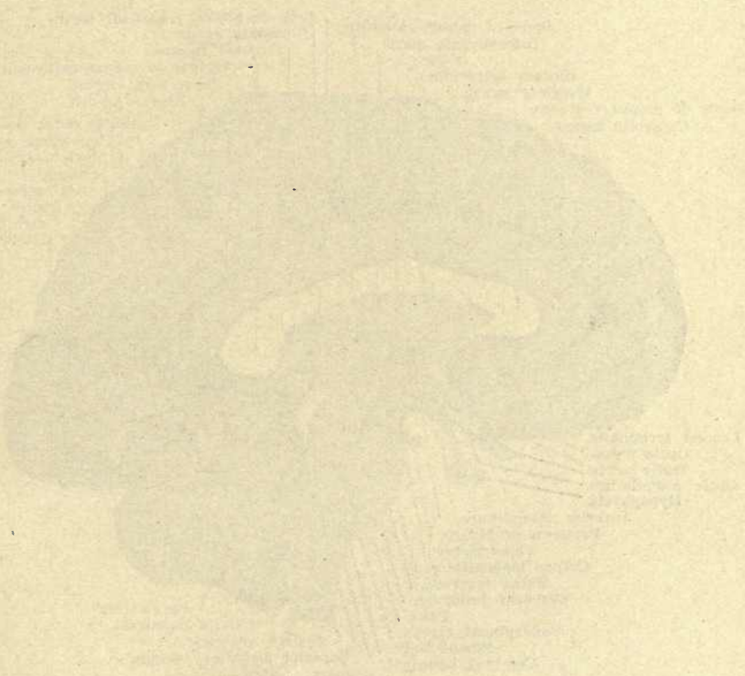


Fig. [illegible]—The [illegible]

between the two [illegible] commissure [illegible]. This [illegible] called the [illegible] commissure.

The other commissures [illegible] the middle and posterior commissures. The middle connects the two optic thalami and the latter is situated at the [illegible] end of the [illegible] in relation with the [illegible] of the [illegible] bodies. [illegible] of the [illegible] and the [illegible] in the [illegible]

the brain in this situation and composed of commissural fibers connecting the posterior termination of the visual tracts. The extremities of the commissure are in close relation to the superior corpora quadrigemina.

Above this commissure are the two stalks of the *pineal gland,* which rests upon a flattened triangular surface in front of and

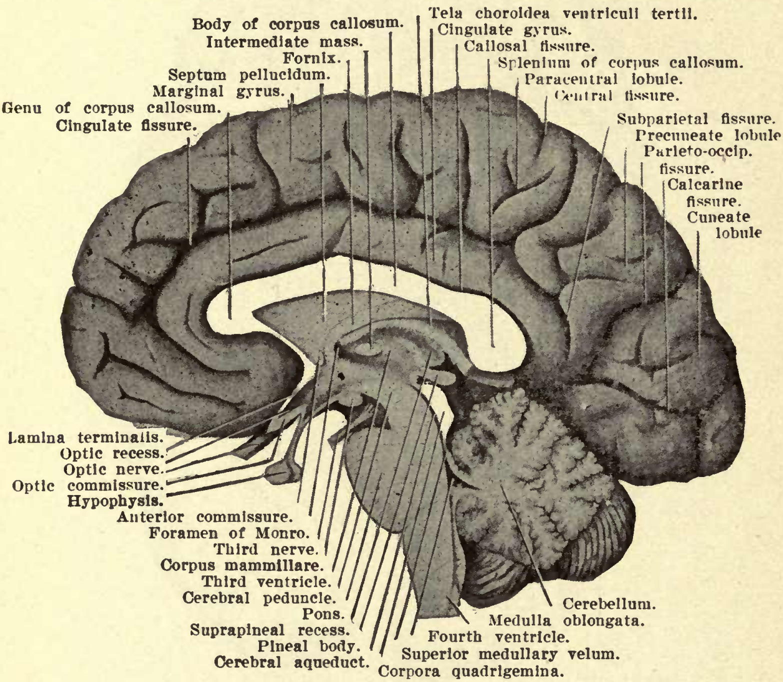


Fig. 80.—Median section of an adult brain. (Quain.)

between the two superior corpora quadrigemina. This surface is called the *trigonum habenulæ.*

Two other commissures cross the third ventricle, *the middle and anterior commissure.* The former connects the two optic thalami, and the latter is situated at the extreme anterior end of the third ventricle at the upper extremity of the anterior perforated space, and is in relation with it. It contains commissural fibers of the olfactory system. One more bilateral band of commissural fibers, the pillars of the fornix and the fornix itself, appears in the third

backwards. Then they [illegible] antero-superior direction. They converge over the septum lucidum, run forward to curve in front of the foramen of Monro, and then reach near the roof of the third ventricle; thereafter they run backwards upon the under surface of the corpus callosum. Diverging as they go backwards from this, laterally they [illegible] external to the third ventricle, [illegible] as the sharp external edge in the roof of the lateral ventricles upon the superior and internal surfaces of the optic thalami. In this situation the roof of the lateral ventricles they are overlapped by a triangular fold of the pia mater [illegible] of the third ventricle [illegible] the latter with its [illegible] and is covered over by the [illegible]. The [illegible] between the fornix and third brain and to the [illegible] of the [illegible]. It is [illegible] in this situation [illegible].

THE CEREBRAL VENTRICLES

Their Development.—The cerebral ventricles are formed by an extension [illegible] forwards and finally backwards, of the anterior extremity of the anterior cerebral vesicle. The lateral ventricles are formed from the evaginations of the lateral walls of the anterior cerebral vesicle and, therefore, belong essentially to the third ventricle.

The Lateral Ventricles.—Inasmuch, however, as the cerebral hemispheres grow from the anterior end of the anterior cerebral vesicle, [illegible] the cavity of the anterior cerebral vesicle, they may be appropriately viewed as representing a pouch-like cavity developed in front of the anterior cerebral vesicle. The so-called lateral ventricle is carried back with the backwardly growing cerebral hemisphere, and is preserved in the adult brain as the lateral ventricles.

The Foramen of Monro.—As the lateral ventricle is thus backward extended from the third ventricle, its connection with the third ventricle is formed laterally on each side of the anterior extremity of the third ventricle. The passage of communication is called the foramen of Monro.

ventricle. They run in an anteroposterior direction. They emerge from the corpora albicans, run forward to curve in front of the foramen of Monro, and then, reaching the roof of the third ventricle, they run backwards upon the under surface of the corpus callosum, diverging as they pass backwards so that ultimately they acquire a position a little external to the third ventricle, appearing by their external edge in the cavity of the lateral ventricle upon the upper and posterior surface of the optic thalami. In this situation on the side of the lateral ventricle they are overlapped by a vascular fold of the ependyma or remnants of the layer of epithelium which originally forms the roof of the third ventricle, before the latter with its ependymal roof is covered over by the backwardly growing hemispheres. The ependyma in this manner becomes enclosed between the fore- and mid-brain and to some extent inverted laterally into the cavity of the lateral ventricle by its rich supply of blood vessels. It is appropriately named in this situation the *velum interpositum.*

THE CEREBRAL HEMISPHERES

Their Development — The cerebral hemispheres are formed by an enormous growth, at first forwards then upwards and finally backwards, of the anterior extremity of the anterior cerebral vesicles. The optic thalami develop from the thickenings of the lateral walls of the anterior cerebral vesicle and, therefore, belong essentially to the third ventricle.

The Lateral Ventricles — Inasmuch, however, as the cerebral hemispheres grow from the anterior end of the anterior cerebral vesicle, preserving within them a continuation of the cavity of the anterior cerebral vesicle, they may be appropriately viewed as representing a *pre-cerebral vesicle,* developed in front of the anterior cerebral vesicle. This so-called pre-cerebral vesicle is carried back with the backwardly growing cerebral hemispheres, and is preserved in the adult brain as the lateral ventricles.

The Foramen of Monro — As the lateral ventricle is carried backward external to the third ventricle, its connection with the third ventricle is placed laterally on each side in the anterior extremity of the third ventricle. The passage of connection is called the foramen of Monro.

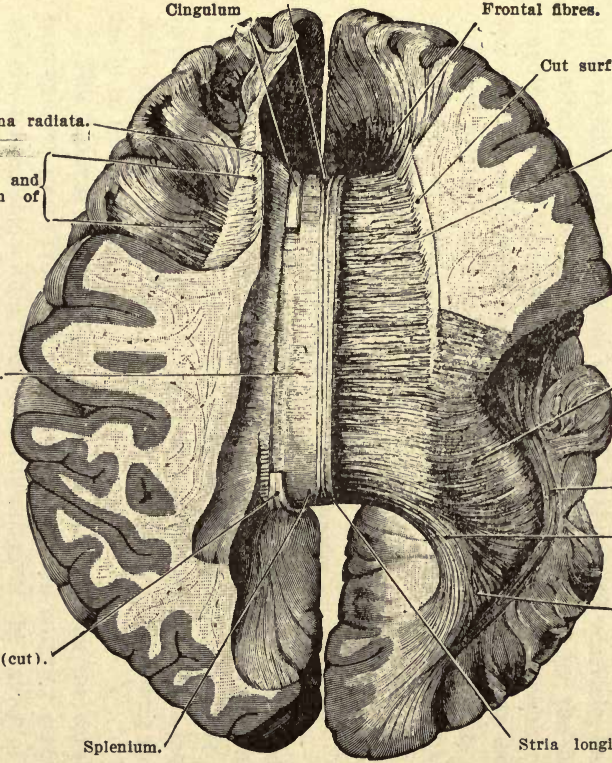


Fig. 81.—The corpus callosum, exposed from above and the right half dissected, to show the course taken by its fibres. (Cunningham.)

The lateral longitudinal stria (which lies near the cingulum) is now shown.

The Body — The lateral ventricle of the brain possesses a body and three horns. (Figs. 82 and 83.)

The body is *roofed over* by the corpus callosum. Its inner wall is bounded by the fornix, overlapped from below by the edge of the

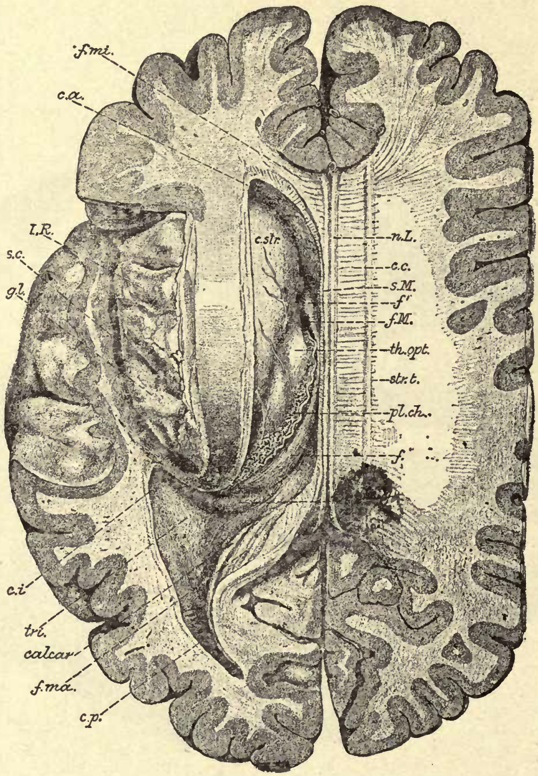


Fig. 82.—View of the lateral ventricle from above. Natural size. (Quain.)

The preparation was made with the brain *in situ* (hardened). The skull cap and membranes having been removed, the brain was sliced down to the level of the corpus callosum. The left lateral ventricle was then opened by cutting away its roof, and the island exposed by slicing away the opercula. The drawing is made from a photograph.

I. R., insula Reilii (the line points to the middle of the three gyri breves); *s. c.*, sulcus centralis insulæ; *g. l.*, gyrus longus insulæ; *c. c.*, corpus callosum; *n. L.*, nerves of Lancisi; *str. t.*, stria tecta; *f. mi.*, forceps minor; *f. ma.*, forceps major; *c. a.*, cornu anterius of ventricle; *c. p.*, cornu posterius; *c. i.*, entrance to cornu inferius; *f. M.*, foramen Monroi; *s. M.*, sulcus leading backwards to the foramen Monroi; *c. str.*, nucleus caudatus of corpus striatum; *th. opt.*, thalamus, anterior tubercle; *pl. ch.*, plexus choroides; *f.*, fornix; *f'*, its column; *h.*, posterior end of hippocampus; *tri.*, trigonum ventriculi; *calcar*, calcar

velum interpositum, called here the *choroid plexus,* because of the vascular folds present in its edge. Its floor, which curves upward externally to meet the roof, is formed from within outward by the

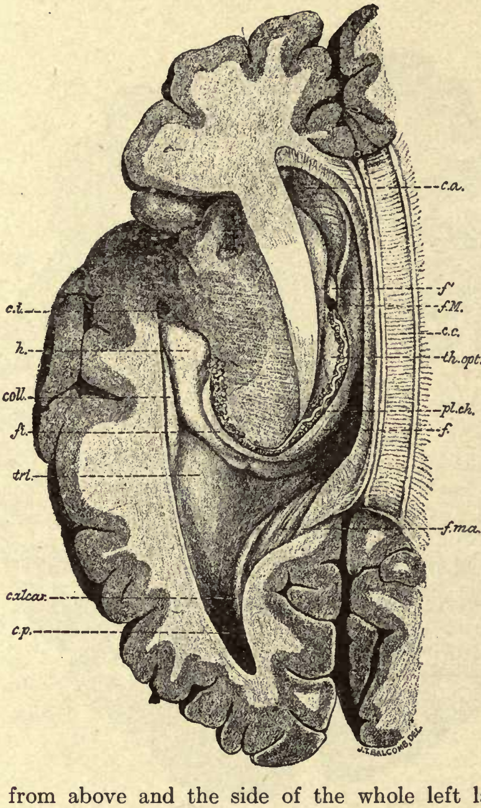


Fig. 83.—View from above and the side of the whole left lateral ventricle. Natural size. (Quain.)

This is a further dissection of the preparation shown in Fig. 82. The insula has been sliced away and the inferior cornu, *c. i.,* exposed. Within this are seen the following parts: *fi.,* fimbria, continued from the fornix; *h.,* the hippocampus; *coll.,* the eminentia collateralis. The other lettering as in Fig. 82.

upper surface of the optic thalamus, the *tænia semicircularis,* a band of white fibers extending from the region of the septum lucidum in front backward and outwards along the external superior border of the optic thalamus, between it and a large elongated

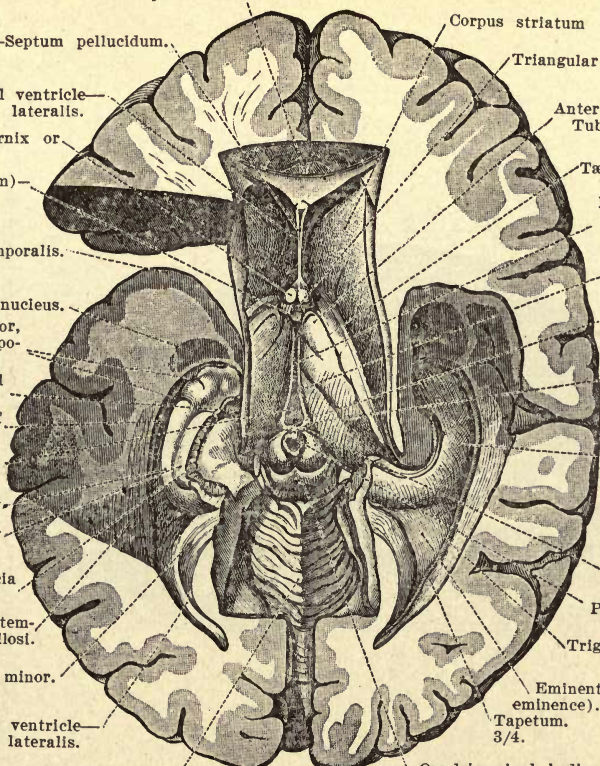


Fig. 84.—The upper part of the cerebral hemispheres, the corpus callosum or great commissure (trans cerebri), the fornix, and the velum interpositum having been removed, the lateral ventricle and the third ventricle were fully opened from above; and the quadrigeminal bodies or optic lobes (corpora quadrigemina), the pineal body or gland (corpus pineale) and also the upper worm or superior vermiform process (vermis superior) of the cerebellum were exposed to view.

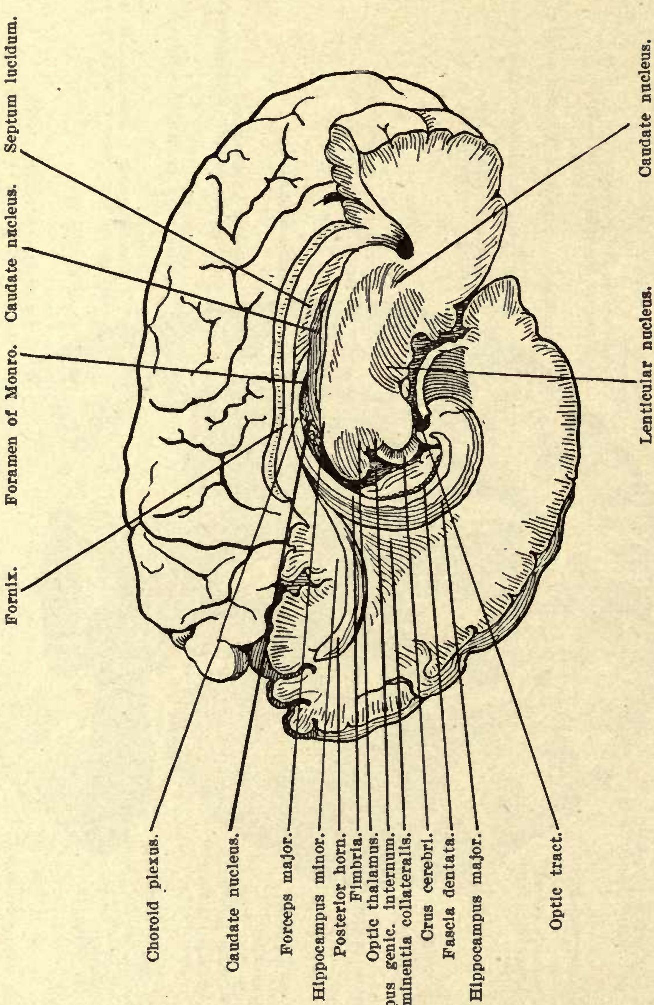


Fig. 85.—Dissection of the descending cornu of the lateral ventricle, with a sagittal section through the basal ganglia.

nucleus of grey matter immediately external to it and called the caudate nucleus.

The Caudate Nucleus. — The caudate nucleus is a mass of grey matter which really develops in the external downwardly curving fibres of the corpus callosum. It follows, therefore, the general shape of the curve of the concave inner surface of this body and, as well, the curve of optic thalami, from the outer border of which it lies separated by the taenia semicircularis.

From within outwards the optic thalamus, the taenia semicircularis, and caudate nucleus form the floor of the body of the lateral ventricle and the *roof of the inferior horns*.

The Anterior Horns — The anterior horns of the two lateral ventricles of the brain arching around the anterior extremity of the optic thalami, are separated from each other by the septum lucidum, which contains the fifth ventricle.

The Posterior and Inferior Horns — Only the space common to both the inferior and posterior horns bounds the posterior extremity of the optic thalamus. The floor of this common region is formed by a rather large, smooth eminence called the *trigonum ventriculi*. Beginning at an area anterior to this eminence and therefore between it and the posterior extremity of the optic thalamus and extending to the tip of the inferior horn along its inner wall, is an elongated, rounded eminence called the *hippocampus major*. It ends anteriorly in a clubbed extremity resembling an animal's paw. Behind the posterior internal aspect of the trigonum ventriculi and, therefore, forming the internal wall of the posterior horn, is another elongated, rounded eminence, the *hippocampus minor*. Another elongated fold or ridge appearing on the inner wall of the posterior horn is the *calcar avis*. It corresponds to an important fissure on the internal surface of the brain. Above it in the angle of the inner wall and roof of the posterior horn is a fold caused by the fibres of the corpus callosum, running to the occipital lobe of the brain. It is called the *forceps major*.

The Hemispheres — The external surface of the brain presents certain important fissures separating convolutions identified with various nervous activities.

The Sylvian Fissure — Upon the external surface is the *Sylvian fissure*. A deep fissure running horizontally backwards from a position corresponding to the posterior border of the lesser wing of

nucleus of gray matter immediately external to it and called the caudate nucleus.

The Caudate Nucleus — The *caudate nucleus* is a mass of gray matter which really develops in the external, downwardly curving fibers of the corpus callosum. It follows, therefore, the general shape of the curve of the concave lower surface of this body and, as well, the curve of optic thalami, from the outer border of which it lies separated by the tænia semicircularis.

From within outwards the optic thalami, the tænia semicircularis, and caudate nucleus form the floor of the body of the lateral ventricle and the *roof of its inferior horns.*

The Anterior Horns — The anterior horns of the two lateral ventricles of the brain, arching around the anterior extremity of the optic thalami, are separated from each other by the septum lucidum, which contains the fifth ventricle.

The Posterior and Inferior Horns — Only the space common to both the inferior and posterior horns bounds the posterior extremity of the optic thalami. The floor of this common region is formed by a rather large, discoid eminence called the *trigonum ventriculi.* Beginning at an area anterior to this eminence and therefore between it and the posterior extremity of the optic thalamus and extending to the tip of the inferior horn along its inner wall, is an elongated, rounded eminence called the *hippocampus major.* It ends anteriorly in a club-like extremity resembling an animal's paw. Behind the posterior internal aspect of the trigonum ventriculi and, therefore, forming the internal wall of the posterior horn, is another elongated, rounded eminence, the *hippocampus minor.* Another elongated fold or ridge appearing in the inner wall of the posterior horn is the *calcar avis.* It corresponds to an important fissure on the internal surface of the brain. Above it in the angle of the inner wall and roof of the posterior horn is a fold caused by the fibers of the corpus callosum, running to the occipital lobe of the brain. It is called the *forceps major.*

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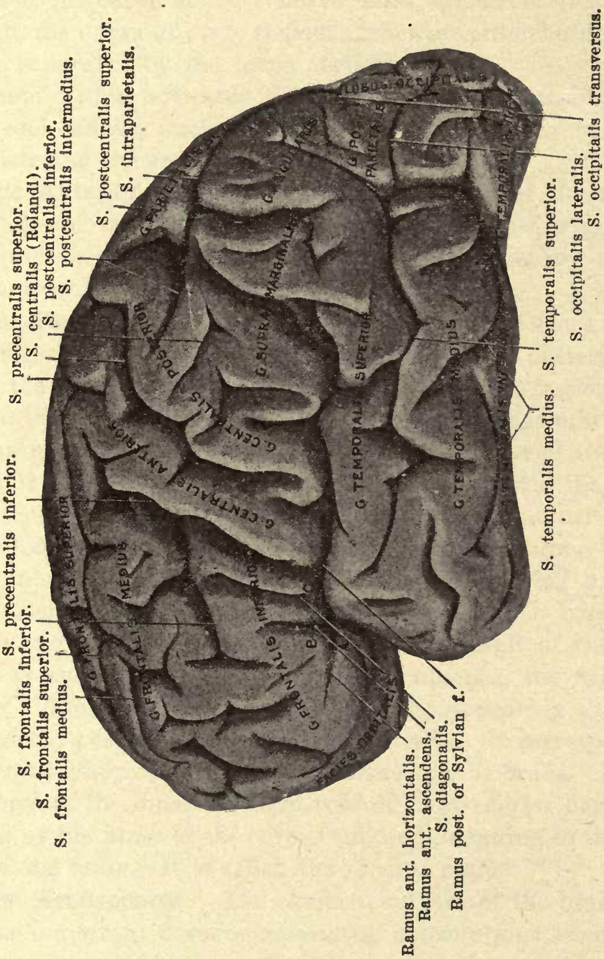


Fig. 86.—Left cerebral hemisphere from the lateral aspect. Natural size. (Quain.)

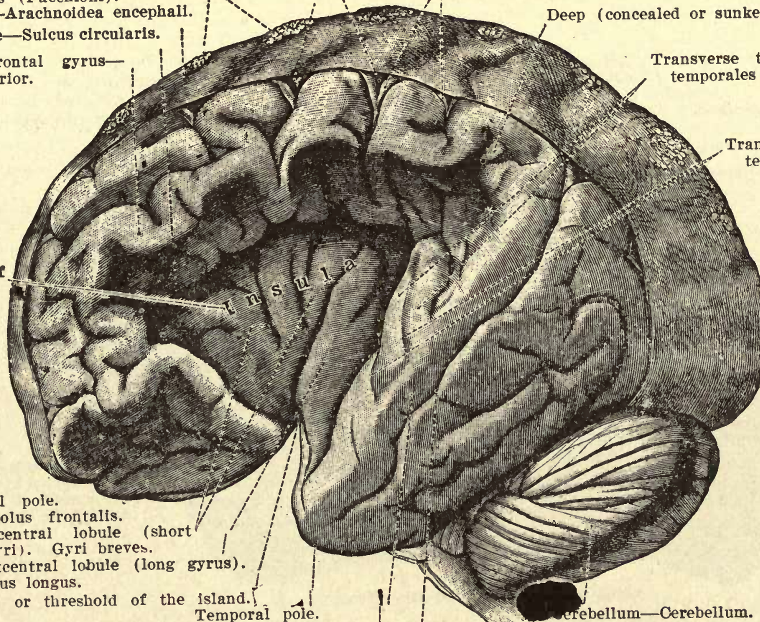


Fig. 87.—The outer or convex surface, facies convexa, of the left cerebral hemisphere, seen from the side.

The temporal lobe has been drawn away as far as possible from the frontal and parietal lobes, so that the sylvian fissure is widely opened, and in the depth of this fissure the central lobe or Island of Reil (insula) with its gyri is displayed, and the transverse temporal sulci and gyri on the upper surface of the temporal lobe are also exposed to view. (Toldt.)

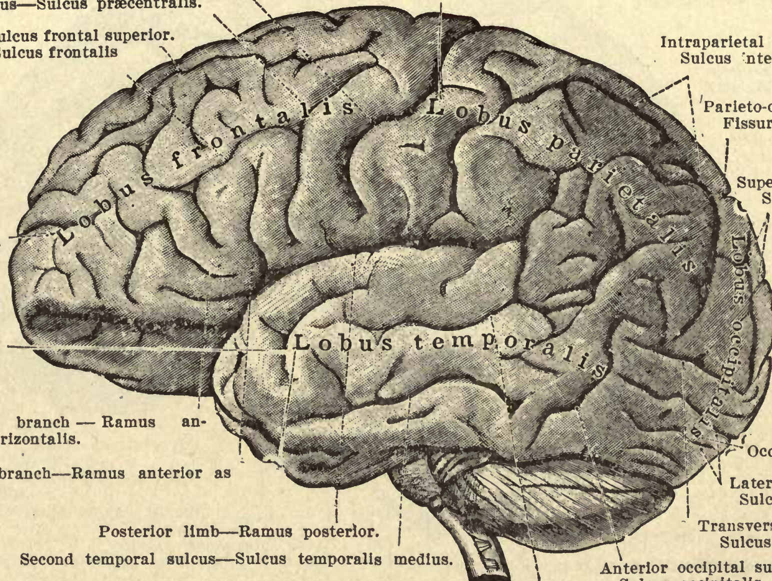


Fig. 88.—The convex or outer surface, facies convexa, of the left cerebral hemisphere, seen from the side. Frontal, parietal, temporal, and occipital lobes. (Toldt.)

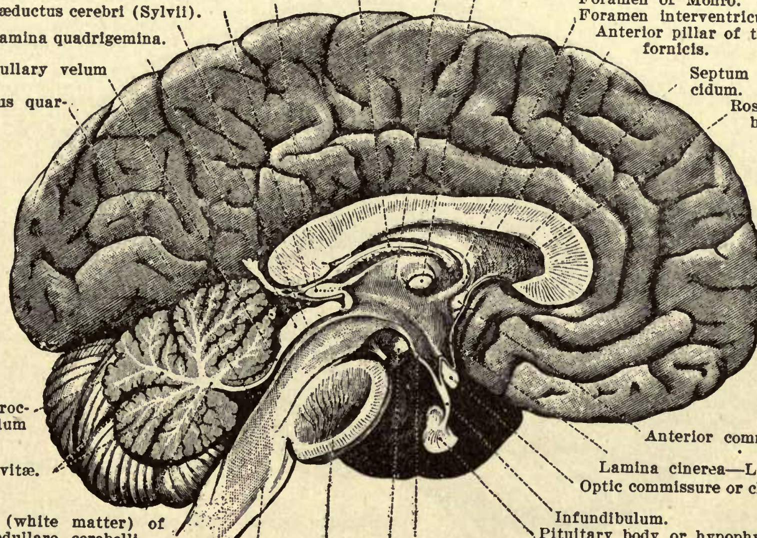


Fig. 89.—Median sagittal section through the brain. The inner or mesial surface, facies medialis, of the left hemisphere. (Toldt.)

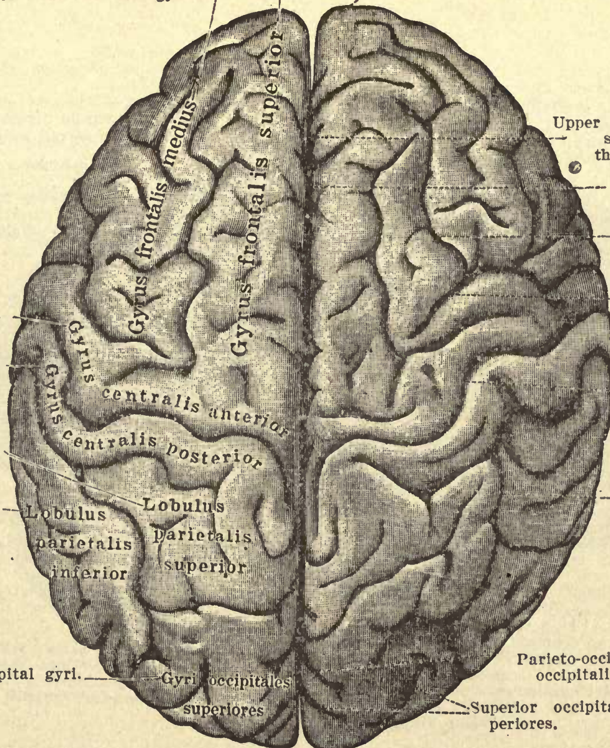


Fig. 90.—The hemispheres of the cerebrum, hemisphæria cerebri; their outer or convex surface, facies convexa, seen from above. Gyri and sulci of the cerebrum.

Dipping deeply between the two hemispheres is the great longitudinal fissure of the cerebrum; on either side of this fissure is the upper mesial border of the hemisphere, which separates the outer or convex surface of the hemisphere from its inner or mesial surface, and extends from the frontal to the occipital pole. (Toldt.)

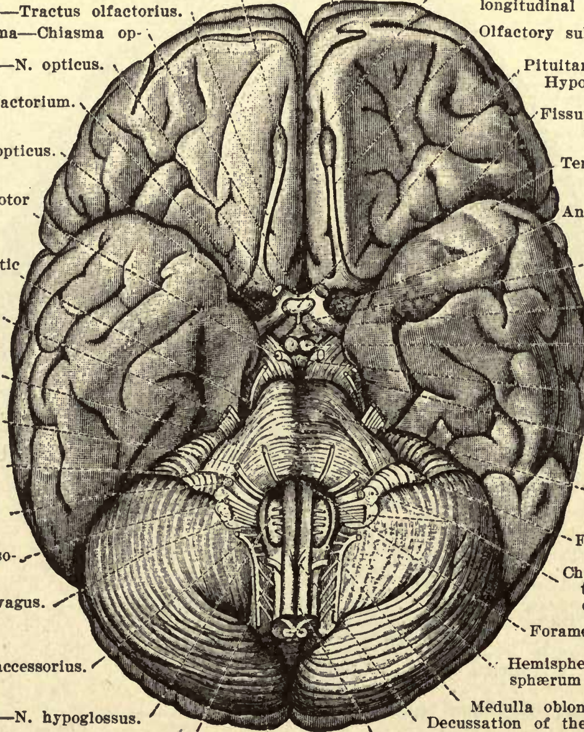


Fig. 91.—The inferior surface (base) of the brain, basis encephali, with the emerging roots of the cranial nerves, radices nervorum cerebralium.

The inferior or basal surface of the cerebrum, facies cerebri. is concealed behind by the cerebellum. (Toldt.)

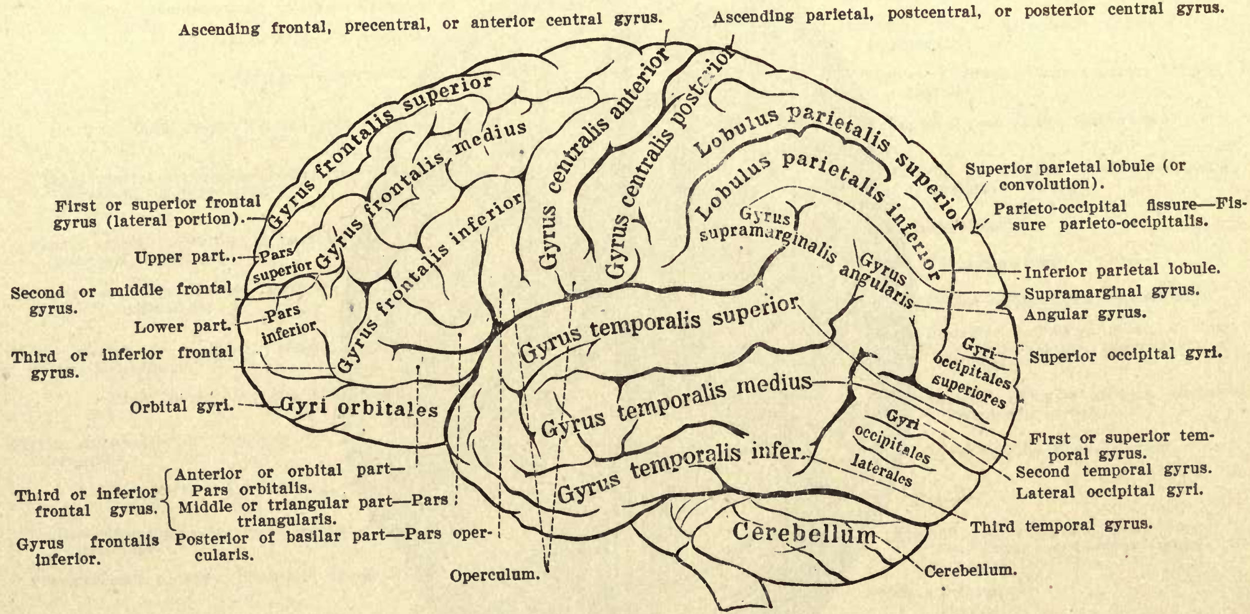


Fig. 92.—The left hemisphere, hemisphærium sinistrum, of the cerebrum; convex or outer surface, facies convexa, seen from the side. Gyri and sulci of the cerebrum. (Toldt.)

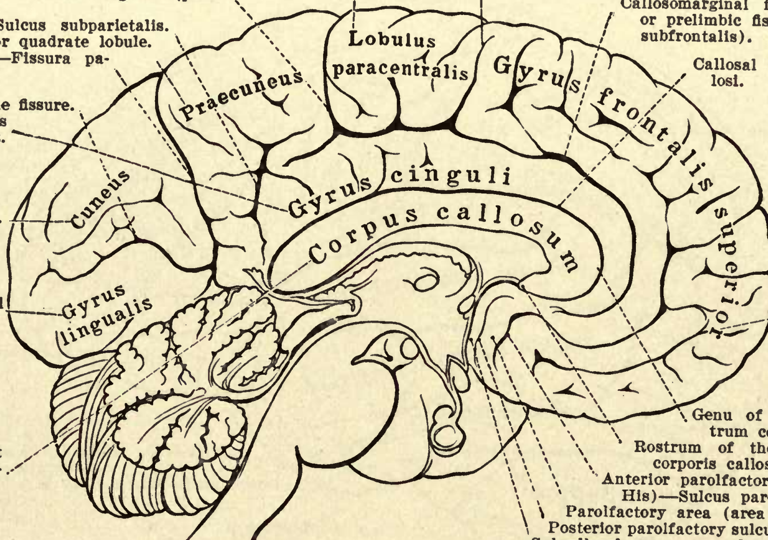


Fig. 93.—Median sagittal section through the brain. Gyri and sulci of the inner or mesial surface (facies medialis) of the left cerebral hemisphere. (Toldt.)

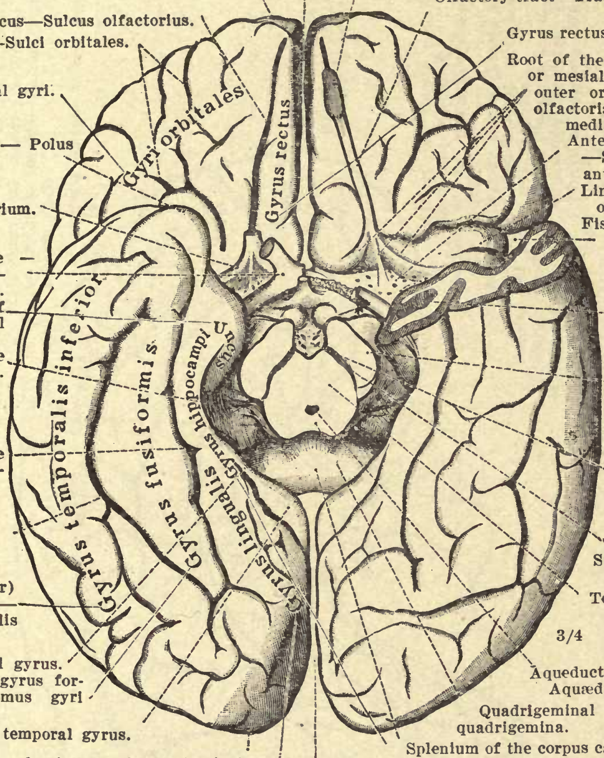


Fig. 94.—The inferior or basal surface of the cerebrum, facies basalis cerebri; the whole extent of this surface is visible, the medulla oblongata, pons varolii, and cerebellum (i.e., the rhombencephalon) having been removed by a transverse section through the mid-brain. Convolutions and furrows of the hemispheres, gyri et sulci cerebri. The frontal, temporal, and occipital poles of the hemispheres.

The anterior extremity of the left temporal lobe has been cut away, the optic commissure or chiasma has been cut through in the median plane, and its left half has been removed. The anterior perforated space has thus been fully exposed on the left side, and its relations to the threshold of the island, limen insulæ, and to the parts of the rhinencephalon situate on the mesial surface of the hemisphere, have been made manifest. The olfactory tract, tractus olfactorius, has been cut away on the right side, in order to display the olfactory sulcus. (Toldt.)

the splenium to terminate in a posterior, upturned extremity in the centre of the parietal lobe. It separates the frontal lobes and anterior portion of the parietal lobes from the temporal lobes.

The Fissure of Rolando. — The *fissure of Rolando*, beginning at a point corresponding on the external surface of the skull to $\frac{1}{2}$ of the distance from the frontal prominence to the occipital tuberosity, it runs downwards and forwards at an angle of 67°, until it nearly reaches the fissure of Sylvius. It separates the frontal from the parietal lobe.

Superior and Inferior Precentral and Intraparietal Fissures. — Fissures parallel to the fissure of Rolando, the superior and inferior precentral fissures in front, and the intraparietal fissure behind separate the ascending frontal convolution from the rest of the frontal lobe and the ascending parietal convolution from the rest of the parietal lobe. The remainder of the external surface of the frontal lobe is composed of three superior, middle and inferior, or first, second and third, frontal convolutions.

Parietal Lobe. — The remainder of the parietal lobe is composed of the superior parietal lobe, contained between the forks of the upper extremity of the intraparietal fissure, the supra-marginal convolution, curving around the posterior upper extremity of the fissure of Sylvius, and the angular convolution which curves around the posterior extremity of the superior temporal fissure.

Superior Temporal Fissure. — The superior temporal fissure runs below and parallel to the fissure of Sylvius and separates the first or superior temporal convolution from the second or middle temporal convolution.

The Boundaries of the Occipital Lobe. — Posterior to the parietal and superior, middle and inferior temporal convolutions is the occipital lobe. It is separated from these lobes on the external surface of the hemisphere by an imaginary line drawn from the point where the parieto-occipital fissure appears on the external surface of the brain and the pre-occipital notch. The last is an indentation on the brain produced by the attachment of the anterior border of the tentorium cerebelli. The frontal, parietal, temporal and occipital lobes are thus seen on the external surface of the brain.

The Calloso-marginal Fissure. — The inferior limit of the frontal lobe on the internal surface of the hemisphere is formed by the calloso-marginal fissure. This fissure is a prominent feature

the sphenoid to terminate in a posterior, upturned extremity in the center of the parietal lobe. It separates the frontal lobes and anterior portion of the parietal lobes from the temporal lobes.

The Fissure of Rolando — The *Fissure of Rolando,* beginning at a point corresponding on the external surface of the skull to .55 of the distance from the frontal prominence to the occipital tubercle, it runs downwards and forwards at an angle of 67½° until it nearly reaches the fissure of Sylvius. It separates the frontal from the parietal lobes.

Superior and Inferior Precentral and Intraparietal Fissures — Fissures parallel to the fissure of Rolando, the superior and inferior precentral fissures in front, and the intraparietal fissure behind, separate the ascending frontal convolution from the rest of the frontal lobe and the ascending parietal convolution from the rest of the parietal lobe. The remainder of the external surface of the frontal lobe is composed of the superior middle and inferior, or first, second and third frontal convolutions.

Parietal Lobes — The remainder of the parietal lobe is composed of the *superior parietal lobe,* contained between the forks of the upper extremity of the *intraparietal fissure;* the *supra-marginal convolution,* curving around the posterior upper extremity of the fissure of Sylvius, and the *angular convolution* which curves around the posterior extremity of the superior temporal fissure.

Superior Temporal Fissure — The superior temporal fissure runs below and parallel to the fissure of Sylvius and separates the first or superior temporal convolution from the second or middle temporal convolution.

The Boundaries of the Occipital Lobe — Posterior to the parietal and superior, middle and inferior temporal convolutions is the *occipital lobe.* It is separated from these lobes on the external surface of the hemisphere by an imaginary line drawn from the point where the *occipito-parietal fissure* appears on the external surface of the brain and the *pre-occipital notch.* The last is an indentation on the brain produced by the attachment of the anterior border of the tentorium cerebelli. The frontal, parietal, occipital and temporal lobes extend over upon the internal surface of the brain.

The Calloso-marginal Fissure — The inferior limit of the frontal lobe on the internal surface of the hemisphere is founded by the *calloso-marginal fissure.* This fissure is a prominent fissure run-

come in contact with the corpus callosum about half way between the latter and the free margin of the internal surface of the hemisphere. The posterior extremity turns upward to [illegible] margin or the internal surface of the hemisphere in the parietal lobe to a point posterior to the middle of [illegible].

The Limbic Lobe.—The calloso-marginal fissure separates the frontal lobe from the gyrus fornicatus or limbic lobe. All of

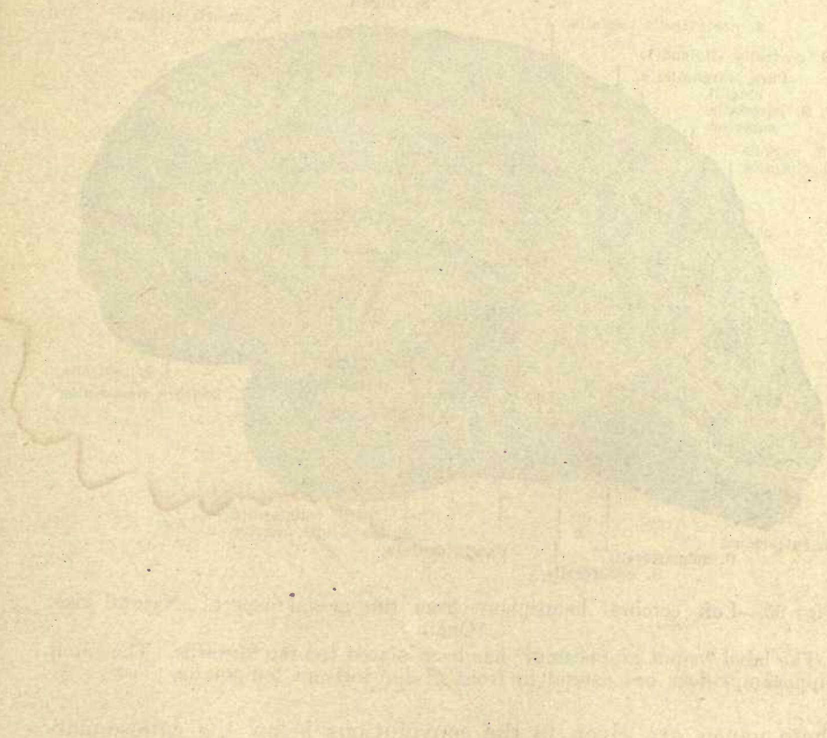


Fig. [illegible].—Left cerebral hemisphere from the mesial aspect. [illegible]

[illegible]

these sulci are seen in the [illegible] figure. [illegible] gyral [illegible]. They are [illegible] with the corpus callosum and curve around its anterior and posterior extremities. Below the [illegible] extremity of the corpus callosum it becomes connected by a narrow [illegible] portion with the [illegible] convolution. This [illegible] portion [illegible] the anterior extremity of [illegible]. The [illegible] posterior [illegible] end of the

ning concentric with the corpus callosum about half way between the latter and the free margin of the internal surface of the hemisphere. Its posterior extremity turns upward to the free margin of the internal surface of the hemisphere in the parietal lobe to a point posterior to the fissure of Rolando.

The Limbic Lobe — The calloso-marginal fissure separates the frontal lobe from the *falciform or cingulate or limbic lobe.* All of

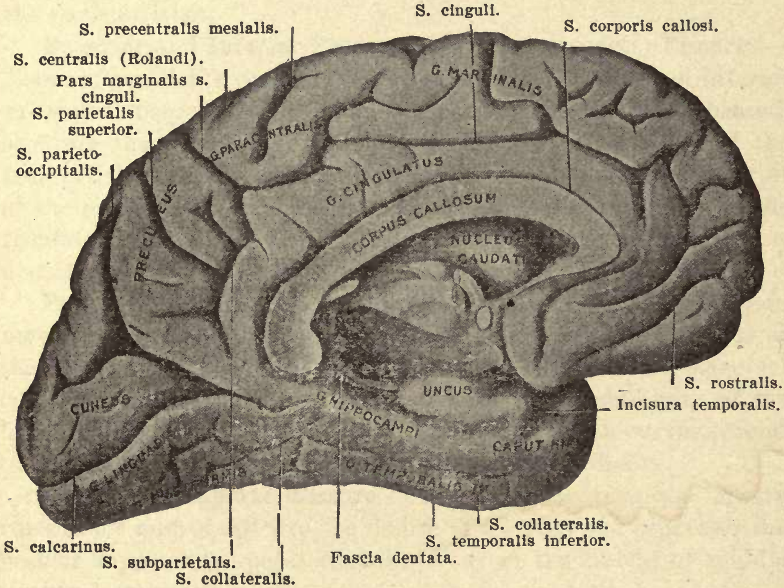


Fig. 95.—Left cerebral hemisphere from the mesial aspect. Natural size. (Quain.)

The label "caput hippocampi" has been placed too far forwards. The caput hippocampi does not extend in front of the incisura temporalis.

these names are given to the convolutions below the calloso-marginal fissure. They are concentric with the corpus callosum and curve around its anterior and posterior extremity. Below the posterior extremity of the corpus callosum it becomes connected by a narrow constricted portion with an anterior second enlarged portion. This enlarged portion ends anteriorly in the *uncus,* which is the anterior extremity of the limbic lobe, marked off by a narrow fissure, the *dentate fissure,* from the rest of the limbic lobe.

The Precuneus — Between the posterior upturned end of the

calloso-marginal fissure and another fissure, the subparietal fissure, which continues the general curve of the calloso-marginal fissure around corpus callosum, is the portion of the parietal lobe which appears on the internal surface of the hemispheres. This portion of the parietal lobe is called the *precuneus.* That portion of the parietal lobe appearing on the internal surface of the hemispheres in front of the precuneus is called the *lobulus quadratus.*

The Occipital Parietal Fissure — Behind the precuneus is the *occipital parietal fissure,* which separates the precuneus from the occipital lobe.

Calcarine Fissure — The occipital lobe is divided into two parts by a deep fissure, curving downwards and backwards from the middle of the occipital parietal fissure toward the posterior pole of the brain. This fissure is called the calcarine fissure.

Above the calcarine fissure the occipital lobe is called the *cuneus* and below but more anteriorly the *lobulus lingualis.*

Collateral Fissure — Beneath the lobulus lingualis, separating it and, more anteriorly, the limbic lobe from the portion of the temporal lobe which appears on the internal surface of the hemisphere, is the *collateral fissure.* It runs horizontally between the lobes which it separates. The dentate fissure, a small fissure in the limbic lobe above and parallel to the collateral fissure produces the prominence of the hippocampus major upon the inner wall of the inferior cornu of the lateral ventricle. The calcarine fissure produces the eminence of the calcar avis on the inner wall of the posterior cornu of the lateral ventricle.

The Fornix — The bundle of fibers forming the fornix terminate posteriorly in hippocampus major and eminentia collateralis — structures to be mentioned later, and appearing in the floor of the descending horn of the lateral ventricle and posterior to the optic thalamus. They are continued through the synapses of the corpora albicans as another bundle, the bundle of Vicq d'Azyr, which curves directly out of the corpora albicans into the optic thalami. (Fig. 96.)

The Character of the Cortex — The external walls bounding the lateral ventricles as a whole, *i.e.,* the later transformation of the precerebral vesicle, become very much thickened in all aspects except the internal, in other words, above, externally, below, in

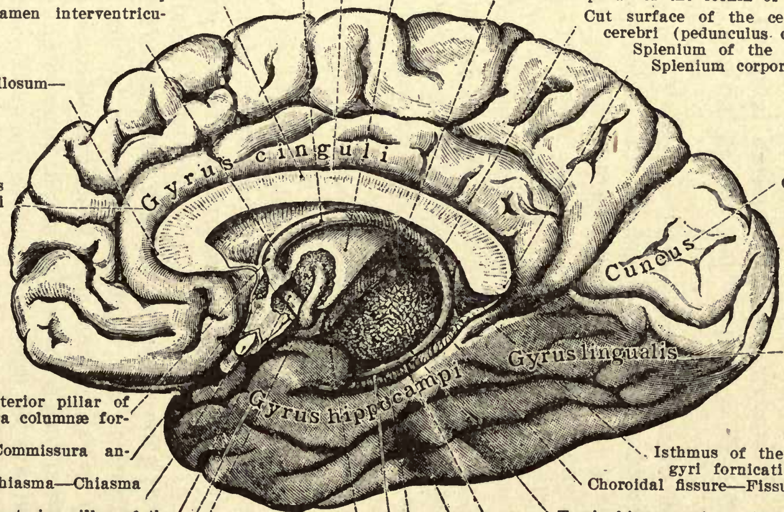


Fig. 96.—The inner or mesial surface, facies medialis, of the right cerebral hemisphere. (Toldt.)

[illegible] and behind. This depression, [illegible] falls on its outer surface, immediately [illegible] gray and white matter of the cerebrum.

The **Fifth Ventricle** is in front of the Foramen of Monro, the [illegible] portion [illegible] and [illegible] that it [illegible] hollow [illegible] which the [illegible] at no time was a part of the system of original cerebral cavities.

This cavity is called the fifth ventricle of the [illegible]. Its walls, which are formed of thin layers of gray matter, are called the septum lucidum.

The Relation of the Optic Thalami to the Lateral Ventricles.—The primarily posterior and [illegible] lateral wall of the lateral ventricle [illegible] the [illegible] of the corresponding [illegible] by growing around the latter. The anterior horn curves around the anterior rounded end of the optic thalamus and the inferior horn curves around the posterior extremity of the optic thalamus and so completely that at the [illegible] its floor is formed by the optic thalamus, while at the [illegible] its roof is formed of the optic thalamus.

The posterior horn curves around in [illegible] direction the posterior extremity of the optic thalamus largely in the same horizontal plane as that of the body of the lateral ventricle.

THE DIFFERENCE BETWEEN THE CORD AND BRAIN

There are two important differences between the internal structure of the cord and that of the medulla, which represent changes in development undergone by the medulla from the manner in which the cord develops.

The first of these is the displacement of the central canal [illegible] until [illegible] forms a [illegible] upon the floor of the fourth ventricle. The second change is the cutting up of the gray matter of the anterior horns by [illegible] the pyramidal tracts crossing the middle line and [illegible] with each other [illegible] they occupy a situation on each side of the anterior median fissure producing two rounded eminences upon the anterior surface of the lower half of the medulla immediately beneath the pons.

As the central canal of the spinal column opens up into the medulla, the gray matter of the posterior horns becomes displaced

front and behind. This thickening, thrown into folds on its outer surface, constitutes the *cortex* and white matter of the cerebrum.

The Fifth Ventricle — In front of the foramen of Monro the brain cortex becomes coapted and united in such manner that it incloses a hollow cavity, which therefore at no time was a part of the system of original cerebral vesicles.

This cavity is called the *fifth ventricle of the brain.* Its walls, which are formed of thin layers of gray matter, are called the *septum lucidum.*

The Relation of the Optic Thalami to the Lateral Ventricles — The primarily posterior and later internal walls of the lateral ventricle inclose the optic thalamus of the corresponding side by curving around the latter. The anterior horn curves around the anterior rounded end of the optic thalamus and the inferior horn curves around the posterior extremity of the optic thalamus and so completely that at the origin of this horn its floor is formed by the optic thalamus, while at its extremity its roof is formed of the optic thalamus.

The posterior horn curves around in an external direction the posterior extremity of the optic thalamus largely in the same horizontal plane as that of the body of the lateral ventricle.

THE INTERNAL STRUCTURE OF THE BRAIN

There are two important differences between the internal structure of the cord and that of the medulla, which represent changes of development undergone by the medulla from the manner in which the cord develops.

The first of these is the displacement of the central canal posteriorly until it no longer forms a canal but a median groove upon the floor of the fourth ventricle. The second change is the cutting up of the gray matter of the anterior horns by fibers of the pyramidal tracts crossing the middle line and decussating with each other until, practically entirely crossed, they occupy a situation on each side of the middle line producing two rounded eminences upon the anterior surface of the lower half of the medulla, immediately beneath the pons.

As the central canal of the spinal column opens up into the medulla, the gray matter of the posterior horns becomes displaced

laterally and the gray matter now in part interspersed between the fibers of the crossing pyramidal tracts, also becomes displaced to a position on each side of the middle line in the floor of the fourth ventricle. Hence it is that the sensory nuclei of the cranial nerves always occupy a more lateral position than the motor nuclei. The cranial nerves may be divided into motor nerves and sensory nerves. A number of them have both sensory and motor roots.

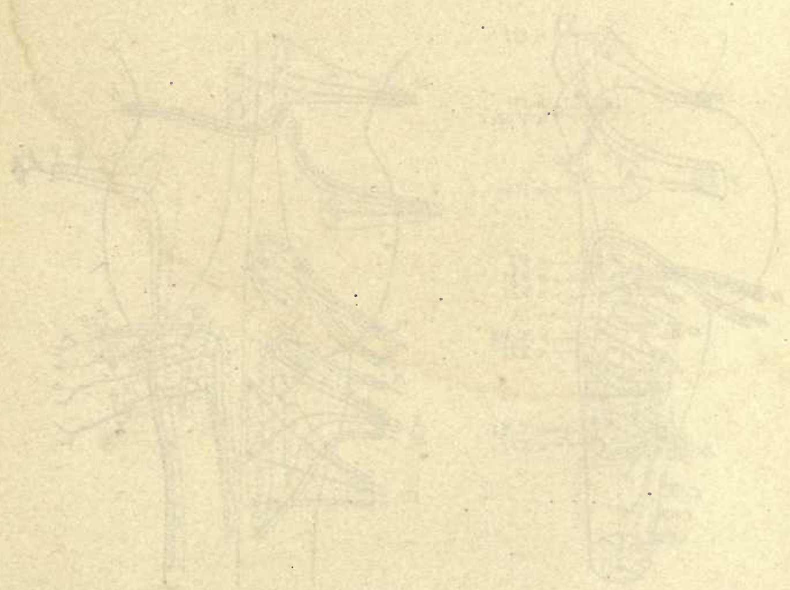


Fig. 95.—Diagrams to illustrate the origin and relations of the true nuclei of the cranial nerves. (Edinger.)
The afferent fibers only illustrated. As shown on the left the motor nuclei and efferent fibers except those of the sympathetic; and on the right side the afferent nuclei, surface view.

The Nuclei and Superficial Origin of the Motor Cranial Nerves (Figs. 97, 98). From below upwards the motor nerves are the twelfth, the eleventh, the motor portion of the sixth, the fifth, the fourth and the third. The nuclei of the twelfth and sixth nerves lie in the gray matter of the floor of the fourth ventricle, close to the middle line, one below and the other above the striae acusticae in just the position which the dislocated gray matter corresponding to the anterior horns of the spinal column should occupy in the medulla.

laterally and the gray matter, now in part interspersed between the fibers of the crossing pyramidal tracts, also becomes displaced to a position on each side of the middle line in the floor of the fourth ventricle. Hence it is that the sensory nuclei of the cranial nerves always occupy a more lateral position than the motor nuclei. The cranial nerves may be divided into motor nerves and sensory nerves. A number of them have both sensory and motor roots.

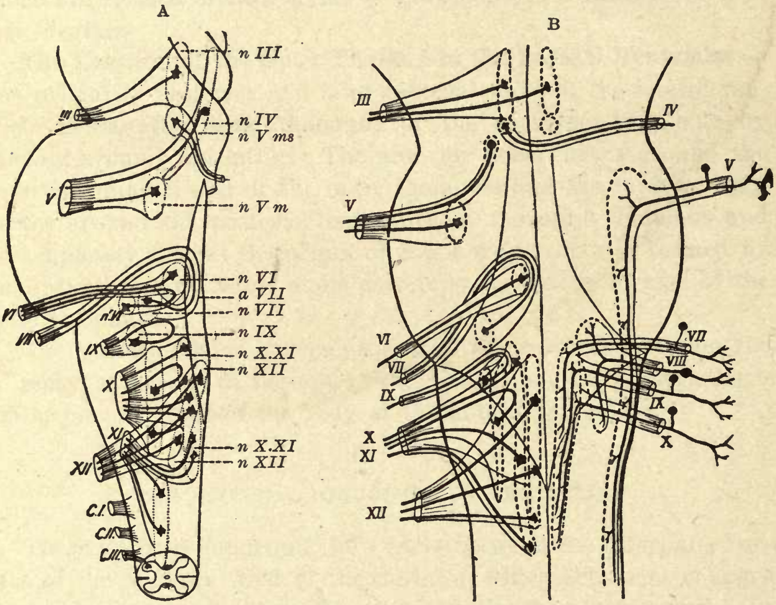


Fig. 97.—Diagrams illustrating the origin and relations of the root-fibres of the cerebral nerves. (Quain.)

A, efferent fibres only; lateral view. *B* shows on the left the motor nuclei and efferent fibres, except those of the fourth nerve, and on the right side the afferent fibres; surface view.

The Nuclei and Superficial Origin of the Motor Cranial Nerves (Figs. 97–100) — From below upwards the *motor nerves* are the twelfth, the seventh, the motor portion of the sixth, the fifth, the fourth and the third. The nuclei of the twelfth and sixth nerves lie in the gray matter of the floor of the fourth ventricle, close to the middle line, one below and the other above the striæ acusticæ in just the position which the displaced gray matter, corresponding to the anterior horns of the spinal column, should occupy as the conse-

quence of the opening out process of the central canal of the spinal column. The nerve fibers arising from the cells of these become collected in bundles which pass outwards and forwards to emerge in a series of roots in the groove between the pyramids and the olivary body.

In the same manner the sixth nerve emerges from the medulla at the lower border of the pons at the upper end of the same groove.

In direct line with these nuclei, close to the iter of Sylvius, is the

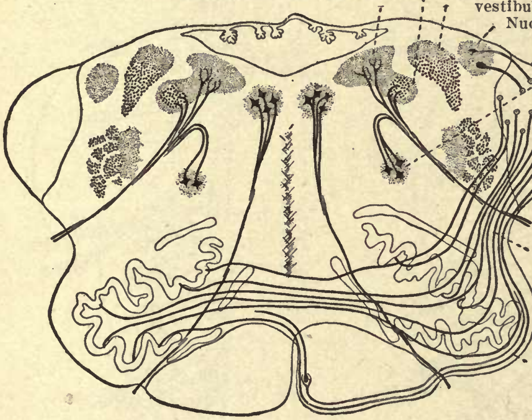


Fig. 98.—Diagram showing the composition of the cerebellar portions of the internal and external arcuate fibres. (Morris.)

column of nerve cells forming the *nuclei of the fourth and third nerves.* The fibers of the fourth nerve become collected into a bundle which passes backwards along the outer side of the nucleus until they reach the upper limits of the medulla where they decussate and, after the crossing, emerge on each side from the groove at the lower margin of the inferior corpora quadrigemina, between this latter and the superior peduncle of the cerebellum. The other cranial nerves possess motor and sensory roots, but the nuclei of the motor roots always lie internal to those of the sensory roots. Thus it is that nucleus of the *vagus or tenth nerve,* which is partly motor and partly sensory, lies under the ala cinerea external to the position of the origin of the twelfth nerve. The motor portion of the tenth arises from a separate nucleus, the *nucleus ambiguus,*

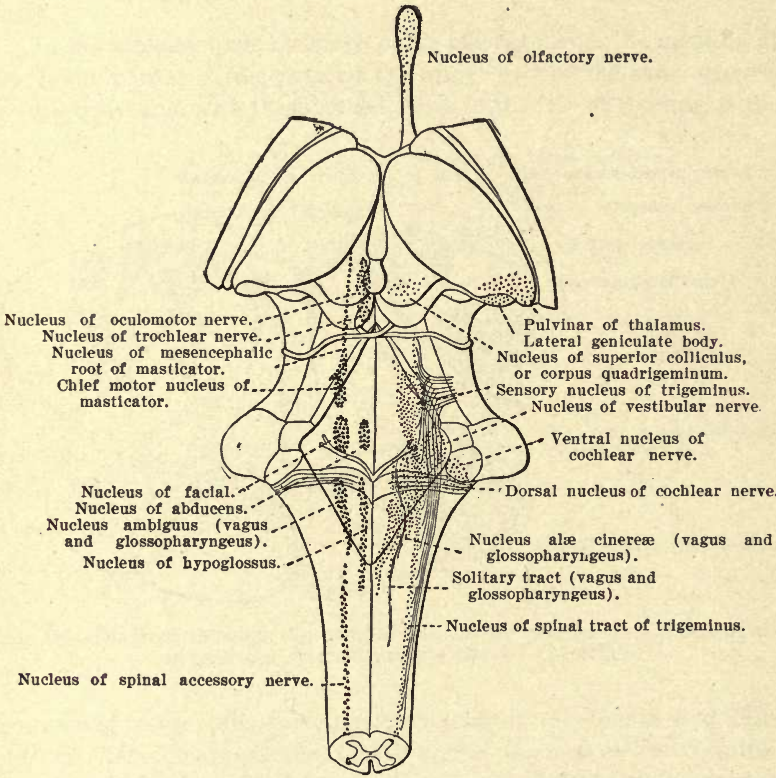


Fig. 99.—Scheme showing the relative size and position of the nuclei of origin of the motor and the nuclei of termination of the sensory cranial nerves. (Morris.)

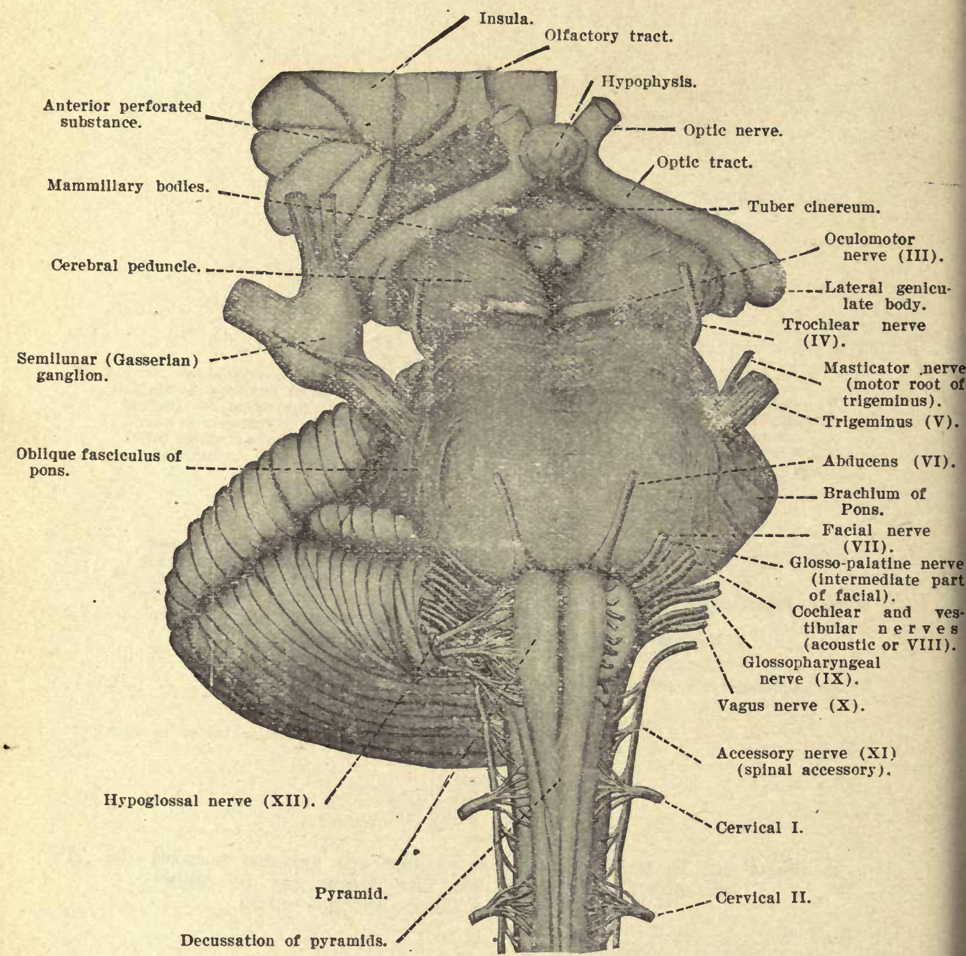


Fig. 100.—Semi-diagrammatic representation of the ventral aspect of the rhombencephalon and adjacent portions of the cerebrum. (Morris.)

which lies internal to the sagittal plane of the main nucleus. The fibers of the *third nerve* pass directly outward and ventral-wards, traversing the substance of the mid-brain to emerge close to the middle line on the ventral surface of the mid-brain between the diverging crura cerebri.

The seventh nerve arises from a nucleus external and ventral to and slightly below the nucleus of origin of the sixth nerve, deeply placed beneath the floor of the upper half of the fourth ventricle. Its nucleus would seem at first sight to be too far laterally placed for a motor nucleus, but its deeper position in the recticular formation explains this apparent irregularity, for it must be remembered that all the motor nuclei of the cranial nerves occupied originally the position of the laterally placed anterior horns and in the opening out process of the central canal of the spinal column they are at first displaced from a lateral position to an internal one. The seventh nerve possesses also a sensory root, which maintains its integrity as a separate bundle of fibers at the superficial origin of the nerve. Its incoming fibers, like other sensory nerves, divide into ascending and descending fibers which terminate around cells continuing the column of the ninth nerve further upwards. The fibers of the main portion of the seventh nerve are motor and become collected into a bundle which forms a peculiar curve, at first downwards and inwards and backwards, then directly upwards and then downwards and outwards and forwards in a manner to completely encircle the nucleus of the sixth nerve. It finally emerges in the groove between the pons and the medulla just anterior to the position of the superficial origin of the eighth nerve.

The Sensory Nuclei — It must of course be remembered that the nuclei of the *sensory nerves* are not to be viewed as nuclei of origin, as is the case with the nuclei of the motor nerves.

The nuclei of the sensory nerves are collections of nerve cells around which the termination of the sensory fibers arborize. Though more deeply placed, the nucleus of the ninth nerve simply continues upwards, the column of cells of origin of the vagus underlying, in the floor of the fourth ventricle, an area beginning in the gray matter of the ala cinereum and extending upwards external to the trigonum hypoglossi to nearly the level of the striæ acusticæ.

The *fifth nerve* possesses a separate motor and sensory portion.

the position of its nucleus reflects the general plan of the other cranial nerves. The motor nucleus is situated at a little depth below the uppermost portions of the [illegible] part of the [illegible] in the extreme lateral position.

This, however, is not a very great distance from the middle line, inasmuch as the fourth ventricle is quite narrow at this level. The column of cells of the main portion of the motor nucleus is continued upwards, forming a [illegible] of gray matter external and ventral to the [illegible] of the fourth [illegible] from which the [illegible] and downwards [illegible] and unites with the fibres of the main motor nucleus. The collected fibres of the motor portion of the fifth nerve emerge from the lateral surface of the pons.

The remaining fibres of the sensory portion of the fifth nerve enter the pons immediately below the motor root. They traverse the substance of the pons and divide into ascending and descending branches. The ascending branches pass to a smaller [illegible] and terminate in [illegible] which lies near the lateral [illegible] of the [illegible] lateral to the motor nucleus [illegible] the floor of the upper angle of the fourth ventricle.

The descending fibres run downwards for a very long distance, indeed down as far as the level of the second cervical nerve. The descending root [illegible] the lateral [illegible] of the [illegible] of the [illegible] In lower levels it lies close to the surface [illegible] of the medulla [illegible] by the fibres of the eighth nerve. Still lower it forms a part of the substantia gelatinosa of Rolando and the tubercle of Rolando, and may be traced as far as the second cervical [illegible]. Most of the fibres terminate in [illegible] situated [illegible] in the [illegible] of the pons [illegible] lying very close to the lateral surface in an area [illegible] by the angle formed by the [illegible] inferior cerebellar peduncle of the cerebellum.

The Eighth Cranial Nerve. The [illegible] nerve [illegible] which are [illegible] at [illegible] but [illegible] terminal [illegible] is the eighth cranial nerve. It is [illegible] to consider

The position of its nuclei follows the general rule of the other cranial nerves. The motor nucleus is situated at a little depth below the uppermost portions of the pontine part of the medulla, at its extreme lateral portion.

This, however, is not a very great distance from the middle line, inasmuch as the fourth ventricle is quite narrow at this level. The column of cells of the main portion of the motor nucleus is continued brainwards, forming a streak of gray matter external and ventral to the nuclei of the fourth and third nerve from which fibers run downwards forming one bundle with the fibers of the main motor nucleus. The collected fibers of the motor portion of the fifth nerve emerge from the lateral surface of the pons.

The incoming fibers of the sensory portion of the fifth nerve enter the pons immediately below the motor root. They traverse the substance of the pons and divide into ascending and descending bundles. The ascending bundles pursue a shorter course and terminate around cells forming a nucleus which lies near the lateral margin of the pons, lateral to the motor nucleus, though not extending much above the level of the upper limits of the fourth ventricle.

The descending fibers run downwards for a very long distance, no less than as far as the level of the second cervical nerve. This descending root occupies a position at first in the lateral boundaries of the pons in the substance of the transversely running fibers of this structure. In lower levels it lies close to the superficial lateral surface of the medulla internal and posterior to the corpus restiforme and crossed laterally by the fibers of the eighth nerve. Still lower it forms a cap at the tubercle of Rolando and the substantia gelatinosa of Rolando, and may be traced as far down as the second cervical vertebræ. Most of its fibers terminate in the chief sensory nucleus, situated dorsally to it in the upper level of the pons, lateral and ventral to the position of the motor nucleus, coming very close to the lateral surface in an area indicated by the angle formed by the superior and middle peduncles of the cerebellum.

The Eighth Cranial Nerve — The only remaining cranial nerve, exclusive of the optic and olfactory tracts, which are not peripheral nerves at all but bundles of nerve fibers comparable to intracerebral tracts, is *the eighth cranial nerve.* It is proper to consider

this nerve in anosmia [illegible] as with the optic and olfactory nerves [illegible] it is so specially representative in its [illegible] that it stands quite apart from the other cranial nerves.

The eighth cranial nerve is composed of two portions, entirely different in function. Both arise in the sensory cells of the inner ear. One bundle of fibers constitutes the auditory division of the nerve and the other the vestibular division. Both divisions

FIG. 107.—Transverse section of the upper part of the medulla. (Ranson.)

[illegible]

however, enter the medulla just beneath the point where [illegible] divides into a dorsal and ventral division which [illegible] (Fig. 107). However, it is only the auditory fibers which divide to [illegible] the vestibular [illegible]. All of the vestibular fibers pass [illegible] the medulla [illegible] into an ascending and a descending portion. Each of these pass to [illegible]

this nerve in a class by itself or with the optic and olfactory nerves as it is so specially proprioceptive in its character that it stands quite apart from the other cranial nerves.

The *eighth cranial nerve* is composed of two portions, entirely different in function. Both arise in the sensory cells of the internal ear. One bundle of fibers constitutes the auditory division of the nerve and the other the vestibular division. Both divisions,

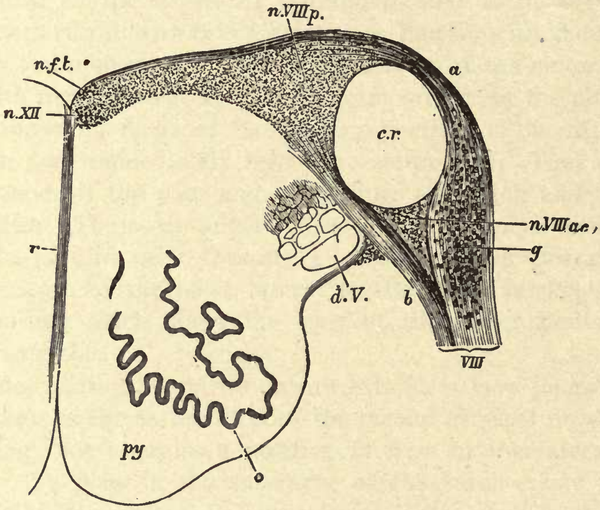


Fig. 101.—Transverse section at the upper part of the medulla oblongata. (Quain.)

py, pyramid; *o,* olivary nucleus; *d. V.,* descending root of the fifth nerve; *VIII,* root of the acoustic nerve, formed of two parts, *a* (cochlear) and *b* (vestibular), which enclose the restiform body, *c. r.; n. VIII p,* dorsal nucleus of the vestibular nerve; *n. VIII ac,* ventral acoustic nucleus; *g,* ganglion-cells of the acoustic tubercle (lateral acoustic nucleus); *n. f. t.,* nucleus of the funiculus teres; *n. XII,* nucleus of the hypoglossal; *r,* raphe.

however, enter the medulla just beneath the pons Varolii as one nerve, parted as they enter the medulla into a dorsal and ventral division which inclose between them the restiform body. (Fig. 101.) However, it is only the auditory fibers which divide to inclose the restiform body. All of the vestibular fibers pass mesoventral to this structure. After it has entered the medulla the vestibular division divides, like other sensory nerves, into an ascending and descending portion. Both divisions pass to the cells underlying

the area in the floor of the fourth ventricle, beneath the ependyma [illegible]

The ascending division passes to the upper portion and the descending division to the lower portion. From these fibers collaterals pass to two other important nuclei: the nuclei of Deiters and Bechterew, placed lateral and ventral to the vestibular nuclei. Many fibers of the vestibular nerve end directly around the cells of these nuclei. The fibers of the ventral division of the eighth

Fig. 112.—Plan of the central connections of the fibres forming the cochlear root of the eighth or auditory nerve.

[illegible]

nerve divide to form the restiform body. The dorso-lateral fibers end around cells forming a prominence, the tuberculum acusticum, on the posterior surface of the restiform body, just above the [illegible] and in many cases are scattered among the fibers of the dorsal nucleus itself. The striae acusticae (medullares) are composed of fibers originating as the axis cylinders of these nerve cells. They pass medially, crossing the middle line and, therefore, the fibers of the opposite side. As soon as they have crossed to the opposite side they dip down close to the middle line to enter the lateral portions of the lemniscus, to be continued to

the area in the floor of the fourth ventricle, termed the *trigonum acusticum.*

The ascending division passes to the upper portion and the descending division to the lower portion. From these fibers collaterals join two other important nuclei — the nuclei of Bechterew and Deiters, placed internal and ventral to the restiform body. Many fibers of the vestibular nerve end directly around the cells of these nuclei. The fibers of the auditory division of the eighth

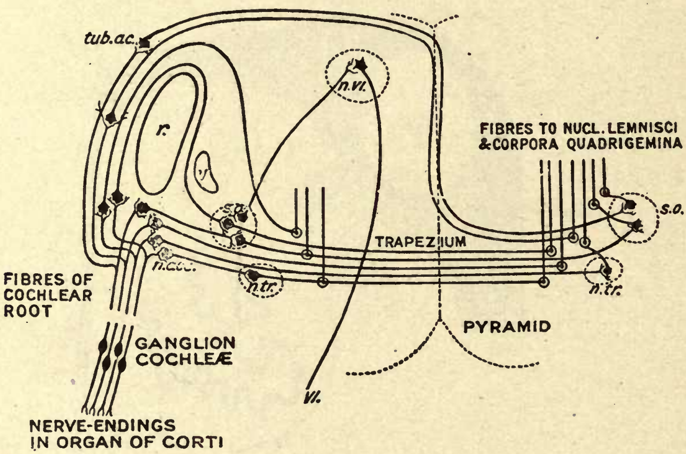
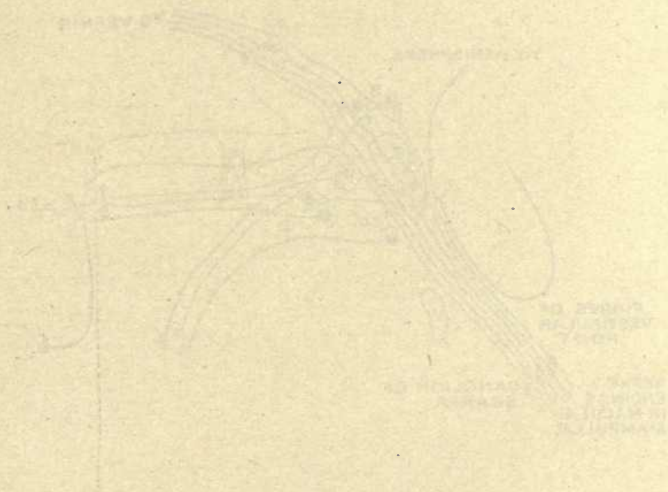


Fig. 102.—Plan of the course of connections of the fibres forming the cochlear root of the auditory nerve. (Quain.)

r., restiform body; *V*, descending root of the fifth nerve; *tub. ac.*, tuberculum acusticum; *n. acc.*, accessory nucleus; *s. o.*, superior olive; *n. tr.*, nucleus of trapezium; *n. VI*, nucleus of sixth nerve; *VI*, issuing root-fibre of sixth nerve.

nerve divide to inclose the restiform body. The *dorso-lateral* fibers end around cells forming a prominence, the tuberculum acusticum, on the posterior surface of the restiform body, just above the trigonum acusticum and in many cells interspersed among the fibers of the dorsal division itself. The striæ acusticæ themselves are composed of fibers originating as the axis cylinders of these nerve cells. They pass internally, crossing the middle line and, therefore, the fibers of the opposite side. As soon as they have crossed to the opposite side they dip down close to the middle line to enter the deep portions of the medulla to be continued to

[illegible]



[illegible]

We have now considered the change produced in the medulla by the opening out of the central canal and the effect which this change has produced upon the location of the nuclei of the cranial nerves.

The Nuclei Gracilis and Cuneatus.—It now remains to con-

the inferior corpora quadrigemina in a manner to be subsequently described. (Fig. 102.)

The fibers of the auditory nerve, which pass meso-ventrally to the corpus restiforme, end around cells to the inner and ventral side of this body, for the most part placed between the auditory and vestibular divisions of the eighth nerve. Higher up these cells become continuous with the nuclei of the meso-ventral division. From these nuclei fibers also arise which cross the middle

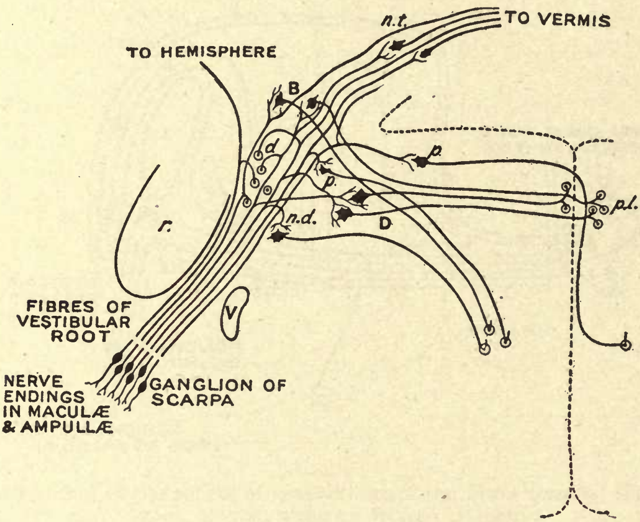


Fig. 103.—Plan of the course and connections of the fibres forming the vestibular root of the auditory nerve. (Quain.)

r., restiform body; *V*, descending root of fifth nerve; *p.*, principal nucleus of vestibular root; *d*, fibres of descending vestibular root; *n. d.*, a cell of the descending vestibular nucleus; *D*, nucleus of Deiters; *B*, nucleus of Bechterew; *n. t.*, nucleus tecti (fastigii) of the cerebellum; *plb.*, posterior (dorsal) longitudinal bundle.

line, deeply decussating in the medulla in a manner to be later described and ultimately reach the inferior corpus quadrigeminum of the opposite side. (Figs. 102 and 103.)

We have now considered the change produced in the medulla by the opening out of the central spinal canal, and the effect which this change has produced upon the location of the nuclei of the cranial nerves.

The Nuclei Cuneatus and Gracilis—It now remains to con-

[illegible] the gray matter [illegible] the nucleus gracilis and [illegible] and the fibers [illegible] course through [illegible] of the [illegible] of the afferent [illegible] nerves and of other [illegible] sensory tracts. The [illegible] [illegible] of the [illegible] half of the medulla oblongata.

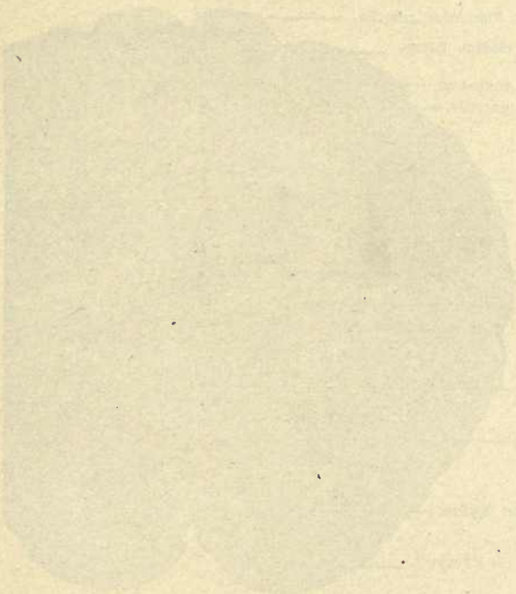


Fig. 193.—Section across the lower part of the medulla oblongata in the middle of the decussation of the pyramids. Magnified. [illegible]

situated on its dorso-lateral aspect, external to the fourth ventricle. They receive [illegible] and [illegible] the terminal arborizations of the fibers of the posterior columns of Goll and Burdach respectively. (Figs. 193 and [illegible].)

Tubercle of Rolando.—Another mass of gray matter [illegible] formed and [illegible] by the [illegible] of the [illegible] of Rolando. This is not a well [illegible] of [illegible] the description [illegible] that [illegible] of Rolando is merely the enlarged upper extremity of the [illegible] substance [illegible] gelatinosa of Rolando [illegible]

sider the new nuclei appearing throughout the medulla and mid-brain and the further course through the medulla and mid-brain of the axis cylinders of these nuclei, of the nuclei of the afferent cranial nerves and of other great sensory tracts. The *first important new masses of gray matter* met with are the *nuclei cuneatus and gracilis,* at the level of the lower half of the medulla oblongata

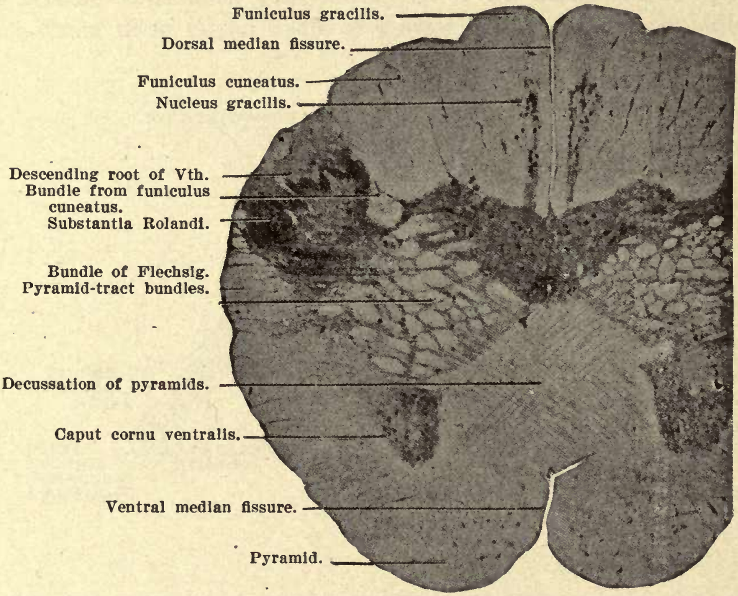


Fig. 104.—Section across the lower part of the medulla oblongata in the middle of the decussation of the pyramids. Magnified about six diameters. (Quain.)

situated on its dorso-external aspect, external to the fourth ventricle. They receive around their nerve cells the terminal arborizations of the fibers of the posterior columns of Goll and Burdach respectively. (Figs. 104 to 107.)

Tubercle of Rolando — Another nucleus of gray matter external and ventral to the nucleus cuneatus is the tubercle of Rolando. This is not a new mass of gray matter but it will make the description clearer to mention it at this place. The tubercle of Rolando is merely the enlarged upper extremity of the gray substance of the substantia gelatinosa of Rolando around

the posterior horns. Around the main [illegible] many fibres of the descending root of the fifth nerve.

Corpus Restiforme (Figs. 108-111). — The tubercle of Rolando appears to be [illegible] bundles [illegible] to form the [illegible] of the inferior peduncle of the cerebellum [illegible]. This body therefore is in the lateral aspect [illegible]

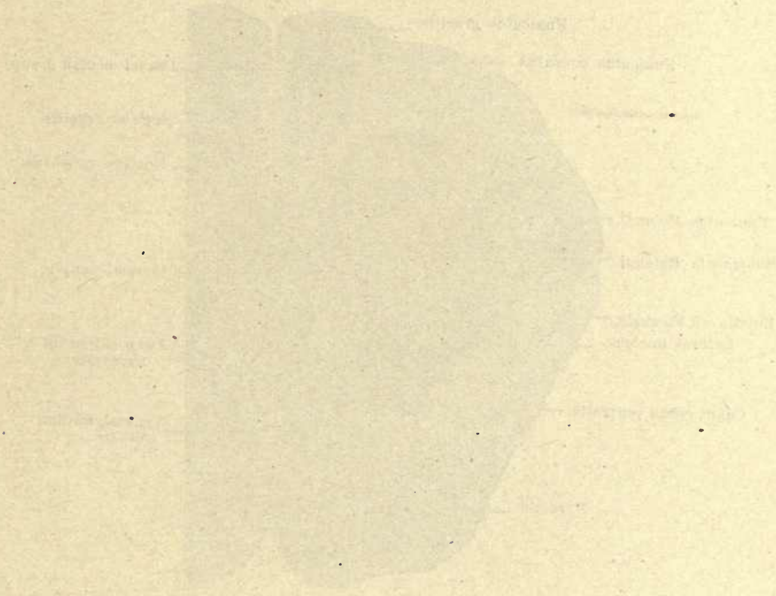


FIG. 111. — [illegible]

of the medulla [illegible] (Figs. 111 and [illegible]) show the [illegible] in the medulla oblongata.

Olivary Nucleus. — [illegible] in the medulla is the olivary nucleus. [illegible] and presents a [illegible] between the [illegible] of the pyramid and [illegible] Rolando [illegible] behind the [illegible] Vagus.

Superior Olive. — The [illegible] small mass of grey matter [illegible] the

the posterior horns. Around its cells doubtlessly terminate many fibers of the descending root of the fifth nerve.

Corpus Restiforme (Figs. 109–111) — The tubercle of Rolando appears to be *overlapped* at its upper extremity by bundles of fibers (*two bundles in particular*) which join to form the beginning of the inferior peduncle of the cerebellum and constitute the *corpus restiforme.* This body, therefore, is in the lateral aspect

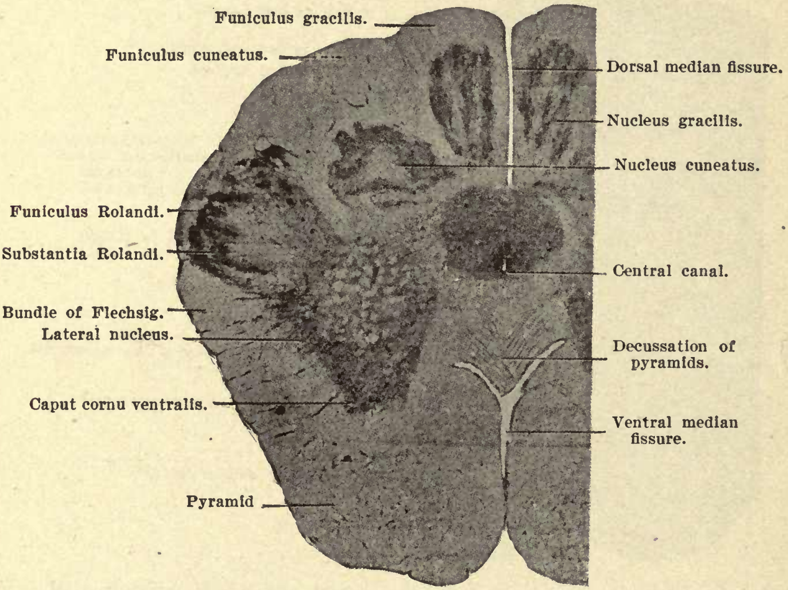


Fig. 105.—Section across the medulla oblongata at the level of the uppermost part of the decussation of the pyramids. (Quain.)

of the medulla, just below the pons Varolii and just above the tubercle of Rolando and the termination of the column of Burdach in the nucleus cuneatus.

Olivary Nucleus — A *third new mass of gray matter* appearing in the medulla is the *olivary nucleus.* It presents a wavy appearance on cross section, arranged in a curved manner, concave internally, and produces a very decided prominence between the prominences of the pyramids and the tubercle of Rolando immediately below the pons Varolii.

Superior Olive — The *fourth new mass of gray matter* is the

superior olivary nucleus, smaller and situated above the main olivary nucleus, in among the transversely coursing fibers of the pons Varolii itself.

Formatio Reticularis — The transversely running fibers of the pons Varolii form a large portion of the pontine portion of the

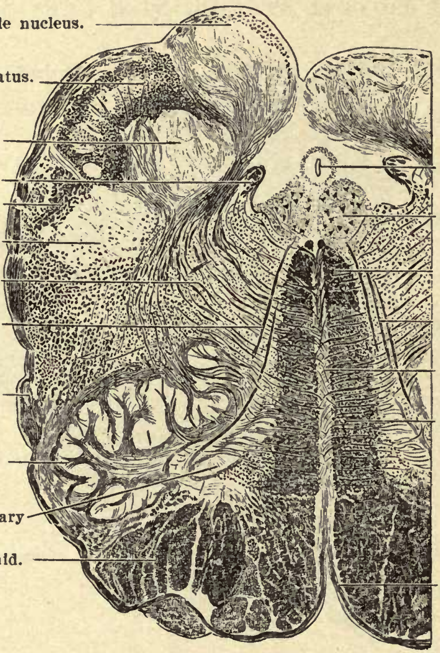
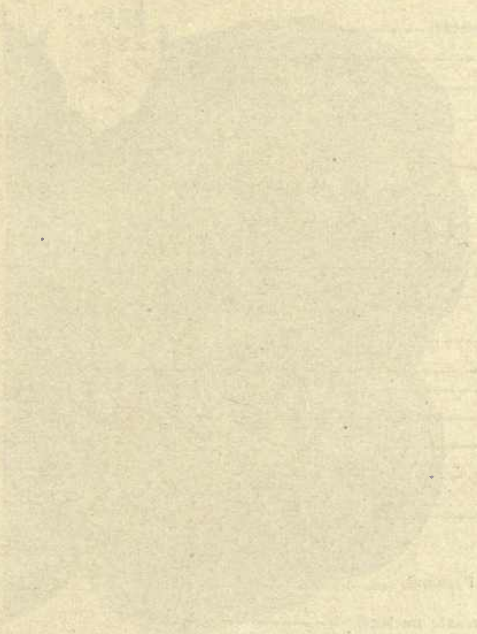


Fig. 106.—Transverse section through the middle of the olivary region of the human medulla oblongata. (Cunningham.)
The floor of the fourth ventricle is seen, and it will be noticed that the restiform body on each side has now taken definite shape.

medulla. They are composed of a large number of interlacing fibers passing between the two hemispheres of the cerebellum. A portion of these fibers are the pyramidal tracts on their way from the brain to the spinal cord. In other words, the fibers of the pyramidal tracts plunge deeply into the pons Varolii and become covered and broken up by the transverse fibers of this structure before they become united again to form the pyramids just above their decussation. Nevertheless, many of the pyram-

[illegible]

and from each [illegible] nucleus. As these fibers [illegible]



[illegible]

[illegible]

The Cerebellum.—[illegible]

[illegible] the mid-brain, the medulla and the fourth ventricle. The cerebel-

idal fibers remain collected in the pons in a fairly well-defined bundle near the anterior surface of the pons. More dorsally other transverse fibers, which at higher levels become longitudinal, spring from the nuclei cuneatus and gracilis. Still other transverse fibers cross the middle line from each olivary nucleus and from each Deiters' nucleus. All these fibers, with others origi-

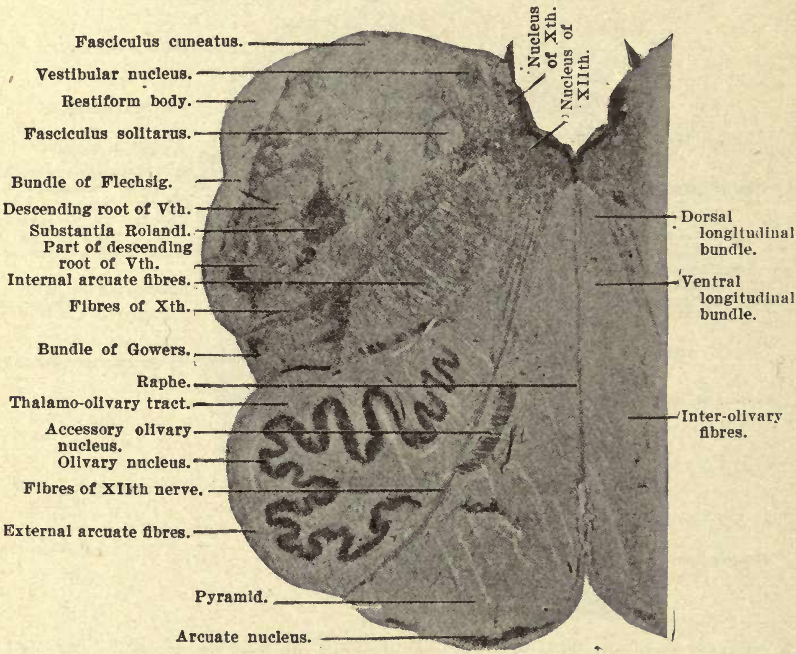


Fig. 107.—Section across medulla oblongata a little above the level of the point of the calamus scriptorius. Magnified about six diameters. (Quain.)

nating from scattered cells among the fibers themselves, form a confused network dorsal to the main mass of fibers of the pons Varolii and constitute what is known as the *formatio reticularis.*

The Cerebellum — The *gray matter of the cerebellum,* with its contained nuclei, must also be considered as additional masses of gray matter added to the primitive segmented cerebrospinal axis of the invertebrates. As explained, it is connected by two superior, two middle and two inferior peduncles, with respectively the mid-brain, the medulla and the fourth ventricle. The cerebel-

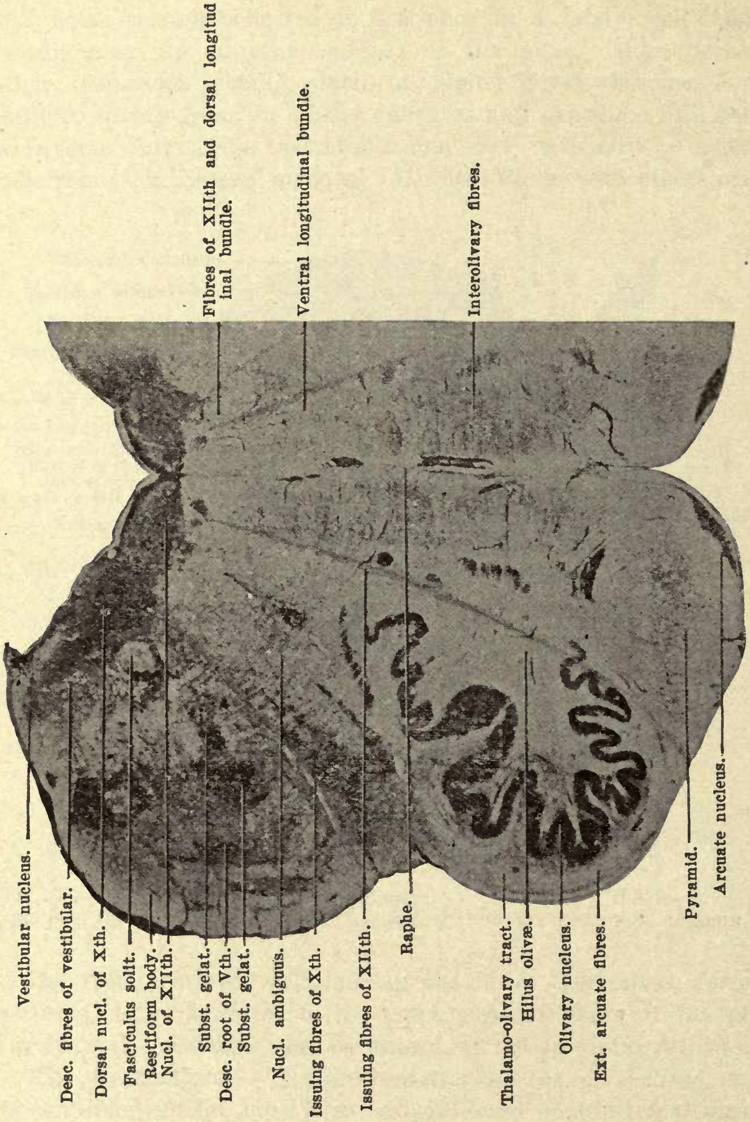


Fig. 108.—Section across the medulla oblongata at about the middle of the olivary body. Magnified about six diameters. (Quain.)

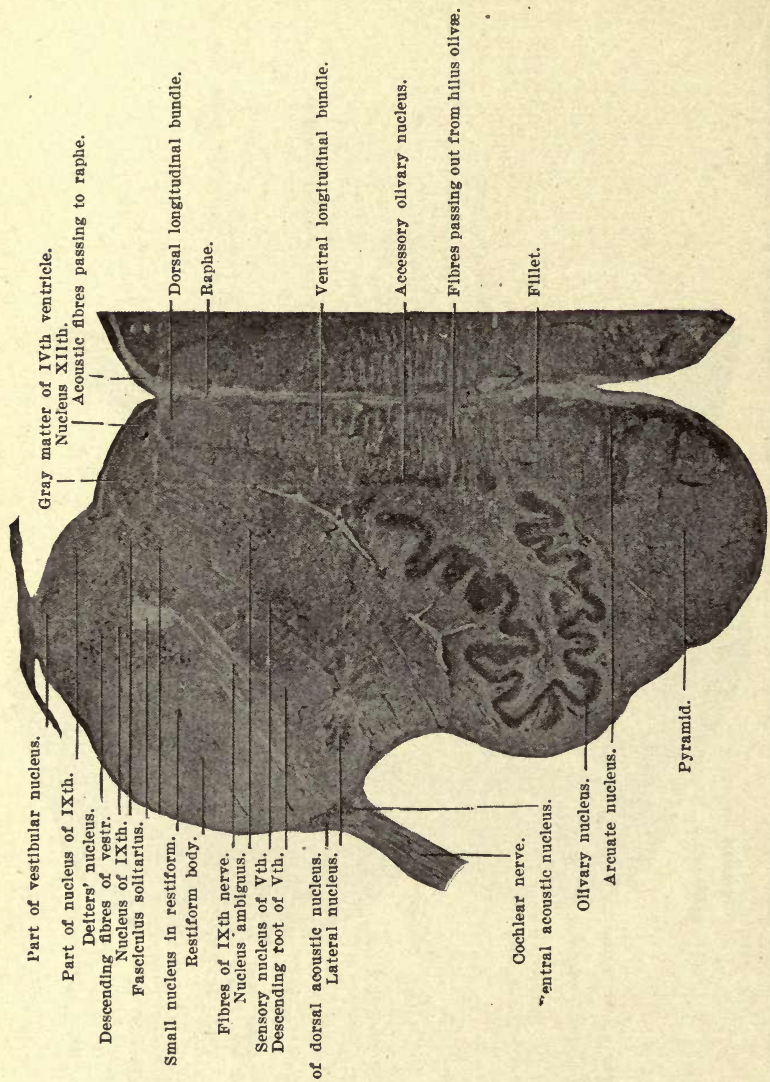


Fig. 109.—Section across the upper part of the medulla oblongata at the level of the eighth nerve. Magnified about six diameters. (Quain.)

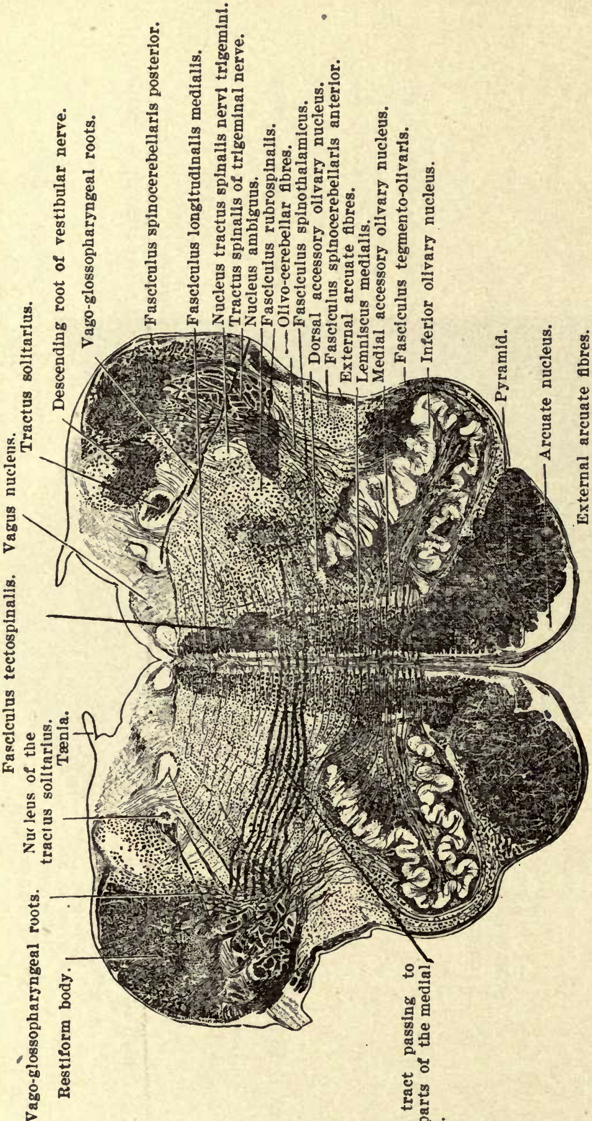


Fig. 110.—Transverse section through the human medulla oblongata in the inferior olivary region. (Cunningham.)

lum itself is composed of two lateral hemispheres and a central lobe which latter appears as rounded eminences on the superior and inferior surface of the cerebellum between the lateral hemispheres. These eminences are termed the superior and inferior

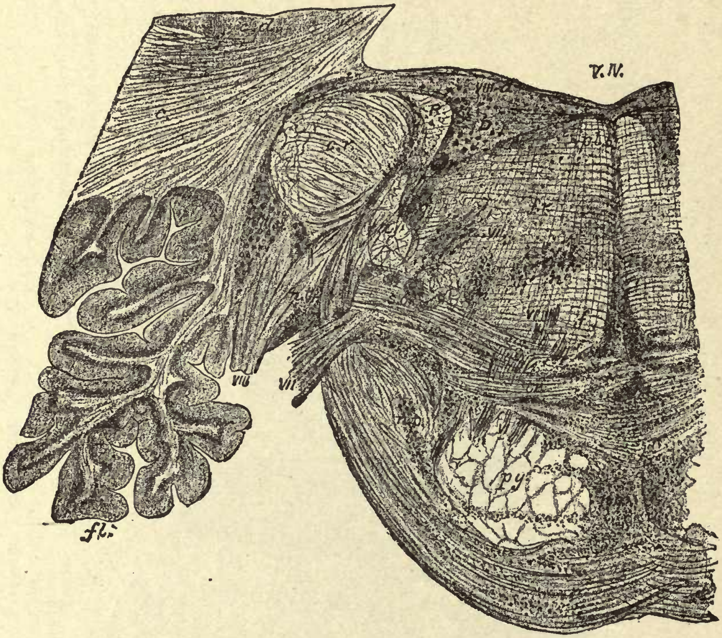


Fig. 111.—Transverse section of pons through the origin of the auditory nerve. From a photograph. Magnified about four diameters. (Quain.)

v. IV, fourth ventricle; *c.*, white matter of cerebellar hemisphere; *c. d.*, corpus dentatum cerebelli; *fl.*, flocculus; *c. r.*, corpus restiforme; *R*, Roller's "ascending" auditory bundle (really formed of descending fibres of vestibular nerve); *D*, Deiters' nucleus; *VIII*, root of auditory nerve; *VIII d.*, principal nucleus of vestibular division; *VIII v.*, ventral nucleus of cochlear nerve; *n. tr.*, small-celled nucleus traversed by fibres of the trapezium; *tr.*, trapezium; *f.*, main fillet; *p. l. b.*, posterior or dorsal longitudinal bundle; *f. r.*, formatio reticularis; *n, n′, n″*, nuclei in formatio reticularis; *V. a.*, so-called ascending root of fifth (really descending); *s. g.*, substantia gelatinosa; *s. o.*, upper olivary nucleus; *VII*, issuing root of facial; *n. VII*, nucleus of facial; *VI*, root-bundles of abducens; *py.*, pyramid-bundles; *n. p.*, nuclei pontis.

vermis. (Figs. 120–122.) The entire surface of all lobes is composed of gray matter, thrown into folds for the purpose of increasing its surface.

Its Nuclei — In the center of each lateral hemisphere is placed

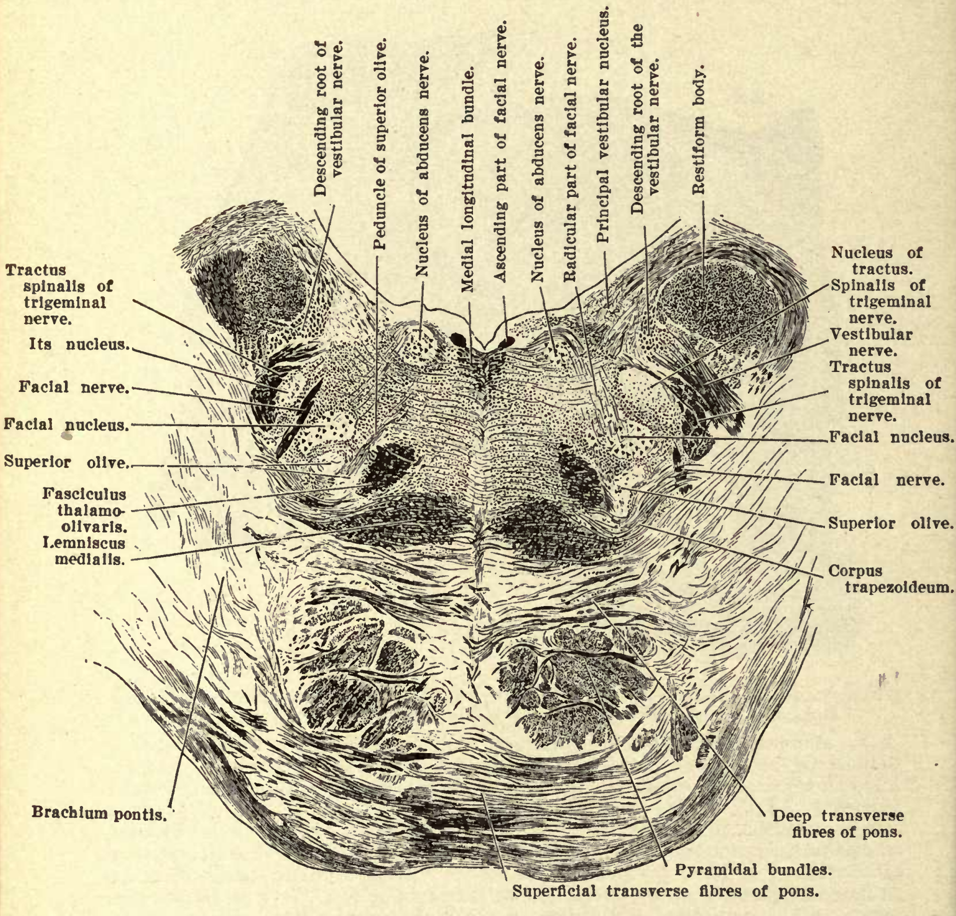


Fig. 112.—Section through the lower part of the human pons immediately above the medulla oblongata. (Cunningham.)

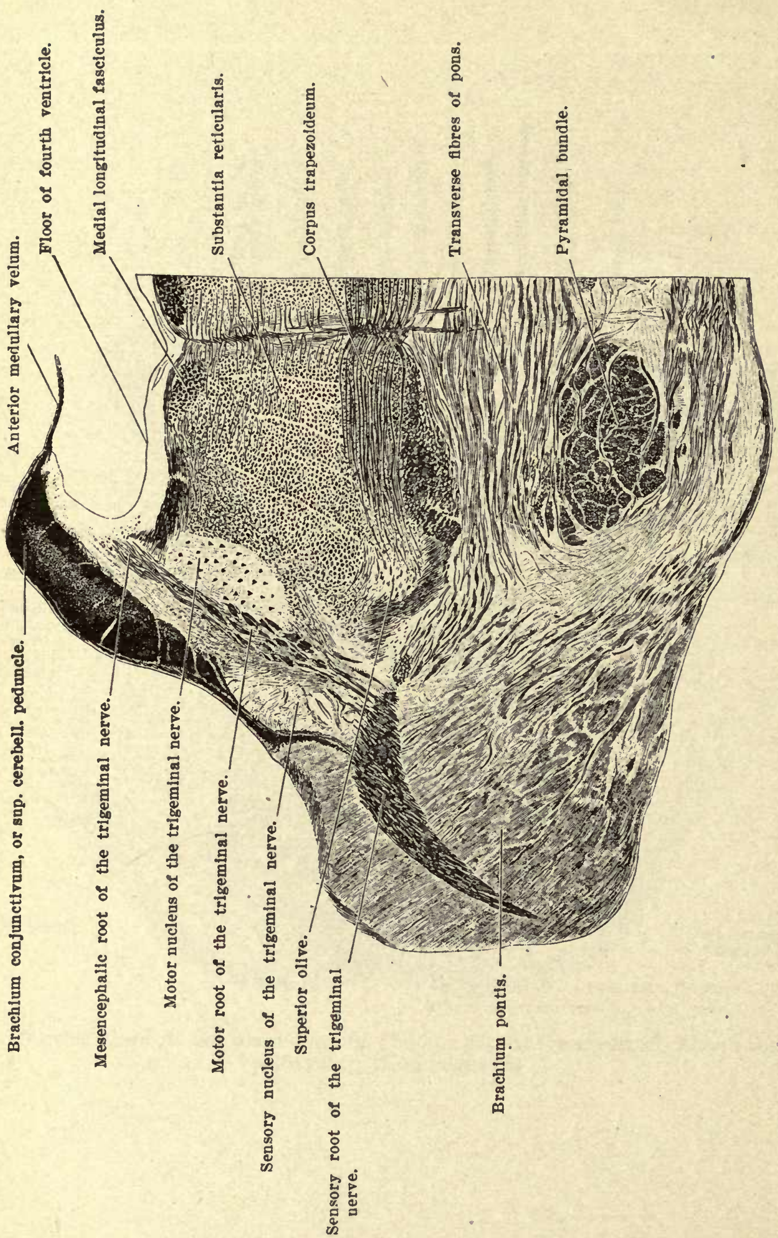


Fig. 113.—Transverse section through the pons at the level of the nuclei of the trigeminal nerve. (Cunningham.)

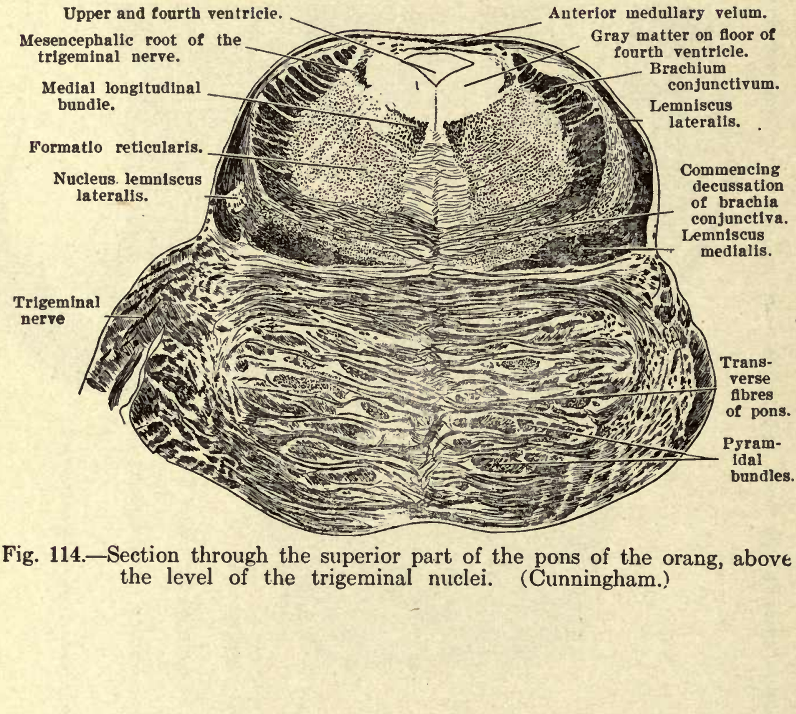


Fig. 114.—Section through the superior part of the pons of the orang, above the level of the trigeminal nuclei. (Cunningham.)

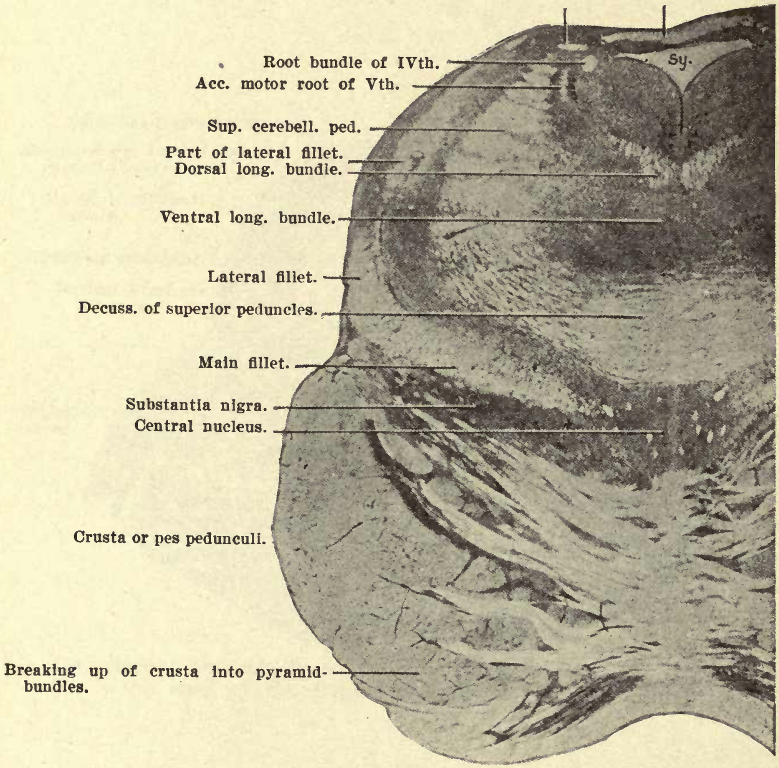


Fig. 115.—Transverse section through the uppermost part of the pons. (Quain.)

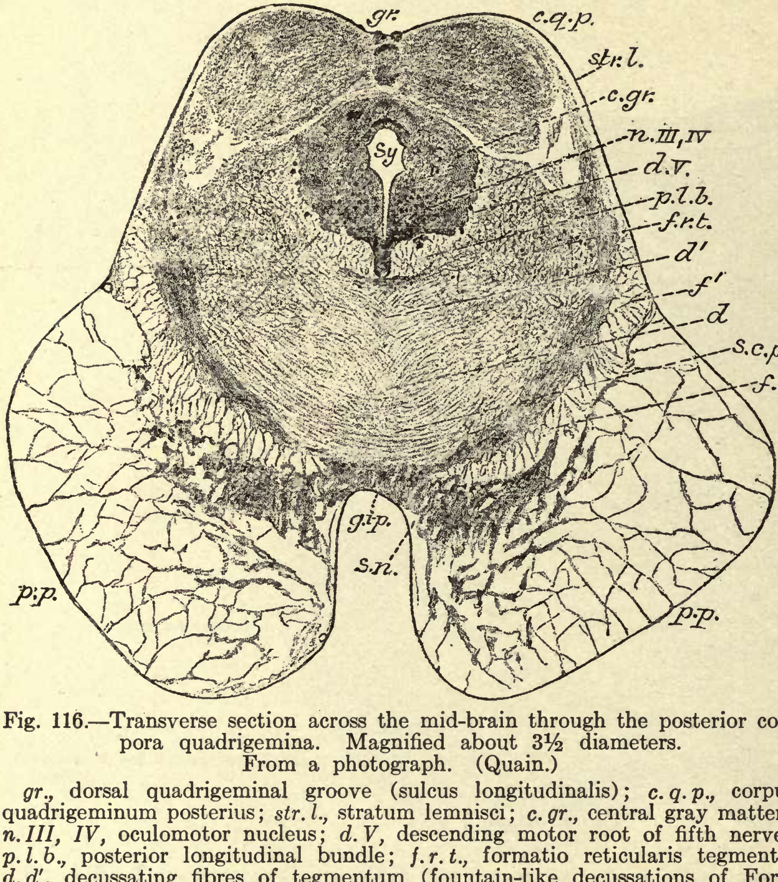


Fig. 116.—Transverse section across the mid-brain through the posterior corpora quadrigemina. Magnified about 3½ diameters. From a photograph. (Quain.)

gr., dorsal quadrigeminal groove (sulcus longitudinalis); *c. q. p.,* corpus quadrigeminum posterius; *str. l.,* stratum lemnisci; *c. gr.,* central gray matter; *n. III, IV,* oculomotor nucleus; *d. V,* descending motor root of fifth nerve; *p. l. b.,* posterior longitudinal bundle; *f. r. t.,* formatio reticularis tegmenti; *d. d',* decussating fibres of tegmentum (fountain-like decussations of Forel and Meynert); *s. c. p.,* decussating fibres of superior cerebellar peduncles; *f,* main fillet; *f',* lateral fillet; *pp.,* crusta pedunculi; *s. n.,* substantia nigra; *g. i. p.,* interpeduncular ganglion; *sy.,* Sylvian aqueduct.

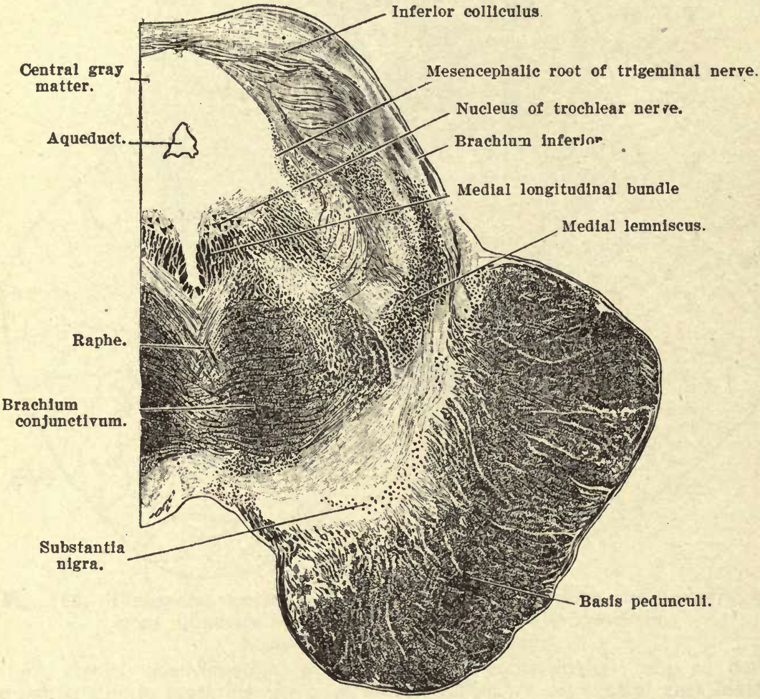


Fig. 117.—Transverse section through the human mesencephalon at the level of the inferior colliculus. (Cunningham.)

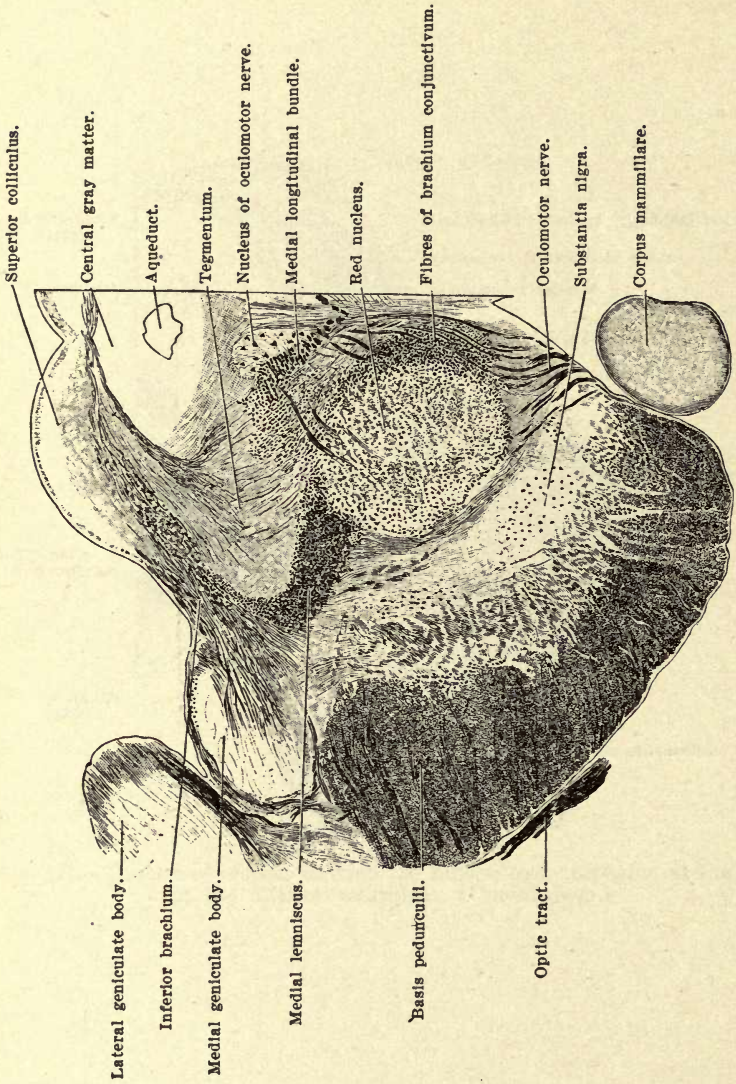


Fig. 118.—Transverse section through the human mesencephalon at the level of the superior colliculus. (Cunningham.)

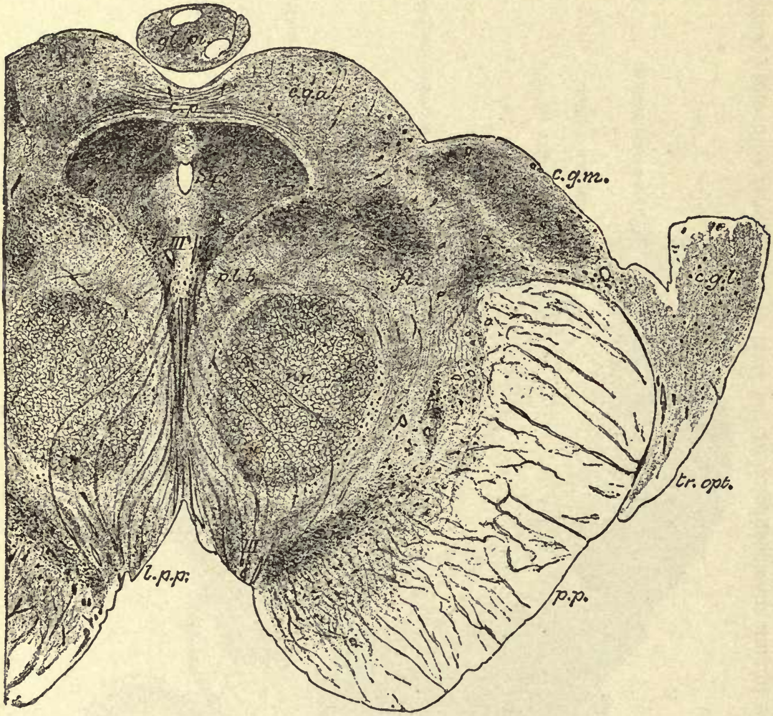


Fig. 119.—Section across the mid-brain, through the anterior corpora quadrigemina. Magnified about 3½ diameters. (Quain.)

Sy., aqueductus Sylvii; *c.p.*, commissura posterior; *gl.pi.*, corpus pinealis; *c.q.a.*, gray matter of one of the anterior corpora quadrigemina; *c.g.m.*, corpus geniculatum mesiale; *c.g.l.*, corpus geniculatum laterale; *tr.opt.*, tractus opticus; *pp.*, pes pedunculi; *p.l.b.*, posterior longitudinal bundle; *fi.*, upper fillet; *r.n.*, red nucleus; *n.III*, nucleus of third nerve; *III*, issuing fibres of third nerve; *l.p.p.*, locus perforatus posticus.

an important nucleus of gray matter, the *dentate nucleus*. On cross section it appears as a wavy, curved line concentric with the surface of the hemispheres.

The central lobe possesses three other nuclei on each side of the middle line. One, the *nucleus fastigii*, is nearest the middle line and immediately above the roof of the fourth ventricle. A third nucleus lies lateral to this. It is named the nucleus globosus.

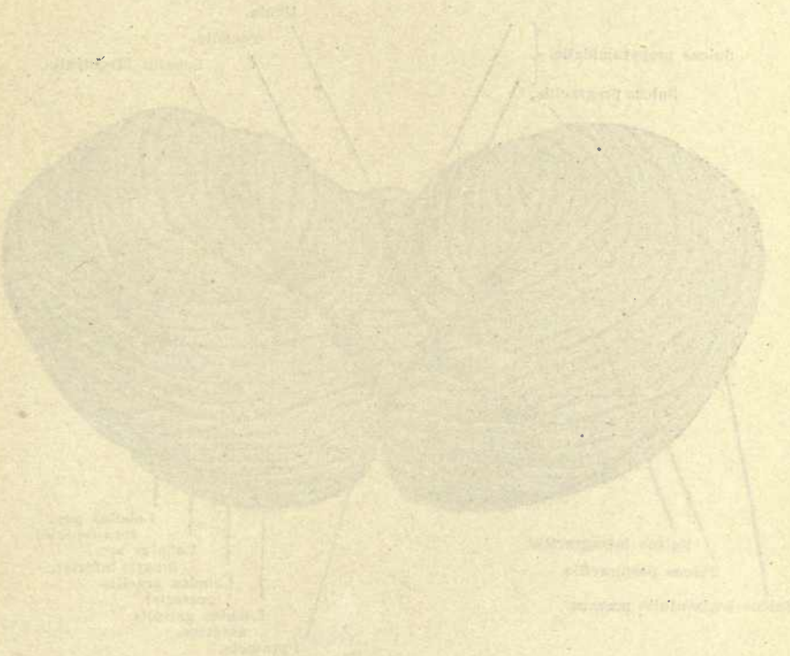


Fig. 130.—View of cerebellum from below. Natural size. (Quain.)

Between it and the dorsal border of the dentate nucleus is still another nucleus, the *nucleus emboliformis*. (Fig. 131.)

The Destination of the Superior Peduncles of the Cerebellum.—After decussation the majority of the fibres of the superior peduncle of the cerebellum terminate in the red nucleus. The upper termination of these fibres really forms a capsule to the red nucleus.

The Red Nucleus.—The red nucleus is situated at the top of

an important nucleus of gray matter, the *dentate nucleus.* On cross section it appears as a wavy, curved line concentric with the surface of the hemispheres.

The central lobe possesses three other nuclei on each side of the middle line. One, *the nucleus fastigii,* is nearest the middle line and immediately above the roof of the fourth ventricle. A third nucleus lies dorsal to this. It is named the *nucleus globosus.*

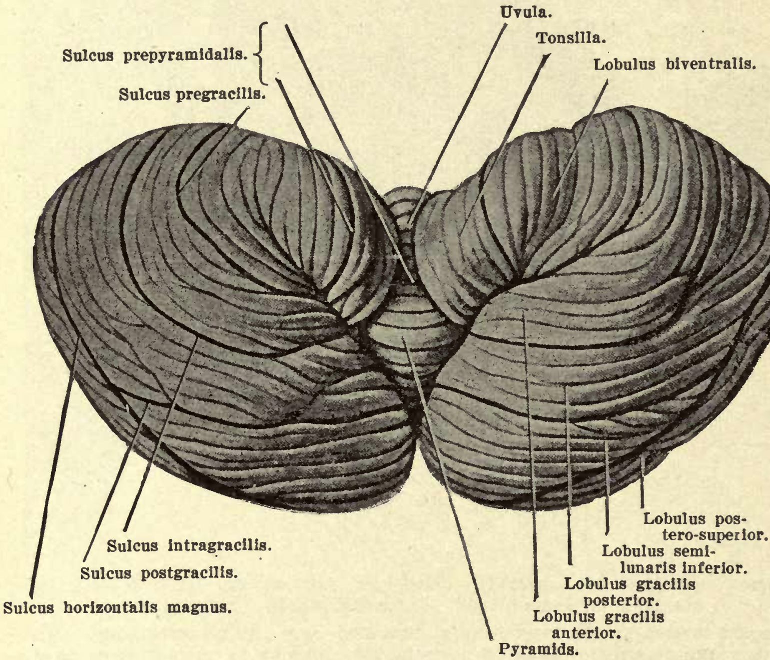


Fig. 120.—View of cerebellum from below. Natural size. (Quain.)

Between it and the dorsal border of the dentate nucleus is still another nucleus, the *nucleus emboliformis.* (Fig. 123.)

The Destination of the Superior Peduncles of the Cerebellum — After decussation the majority of the fibers of the *superior peduncle* of the cerebellum terminate in the red nucleus: The upper termination of these fibers really forms a capsule to the red nucleus.

The Red Nucleus — *The red nucleus is situated* at the top of

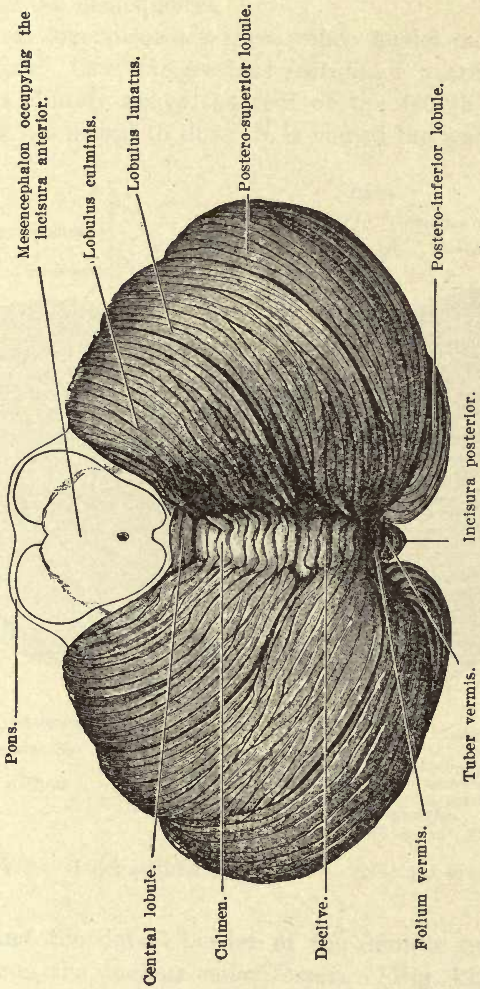


Fig. 121.—Superior surface of the cerebellum. (Cunningham.)

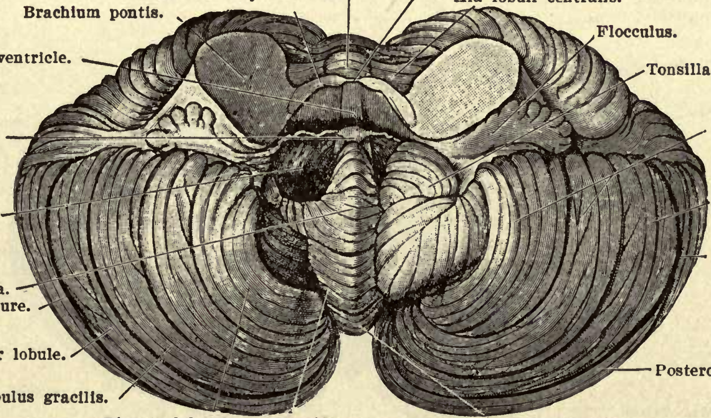
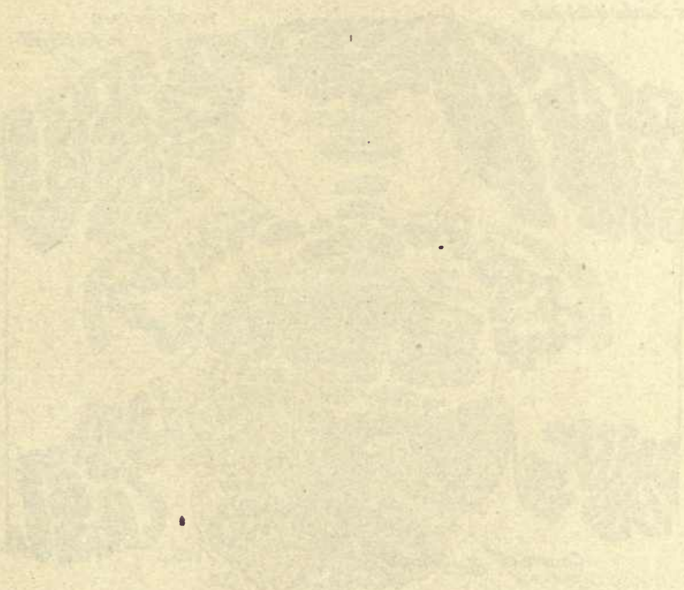


Fig. 122.—Inferior surface of the cerebellum. (Cunningham.)

The tonsil on the right side has been removed so as to display more fully the posterior medullary velum and the furrowed band.

the mid brain, between the [illegible] and [illegible] to the [illegible] and [illegible] and dorsal to the [illegible] of [illegible] It [illegible] and dorsal to the [illegible] of the [illegible] a similar collection of gray matter around the [illegible] (Figs. [illegible] and [illegible]).

Substantia Nigra. — The substantia nigra is found in sections below the level at which the red nucleus is [illegible]. It [illegible] the [illegible] of the [illegible] from the large mass of transversely and longitudinally running fibers [illegible] and com-



[illegible]

[illegible]

[illegible] strands of fibers [illegible] of the [illegible].

The Tegmentum. — Like the [illegible] consists of [illegible] belongs to the [illegible]

the mid-brain, beneath and ventral to the corpora quadrigemina, and dorsal to the inner portion of crura of that side. Lateral to it and dorsal to the external portion of the crus is another collection of gray cells termed the *substantia nigra.* (Figs. 118 and 119.)

Substantia Nigra — The substantia nigra is found in sections below the level at which the red nucleus is formed. It separates the crusta of the cerebrum from a large mass of transversely and longitudinally running fibers, known as the *tegmentum* and con-

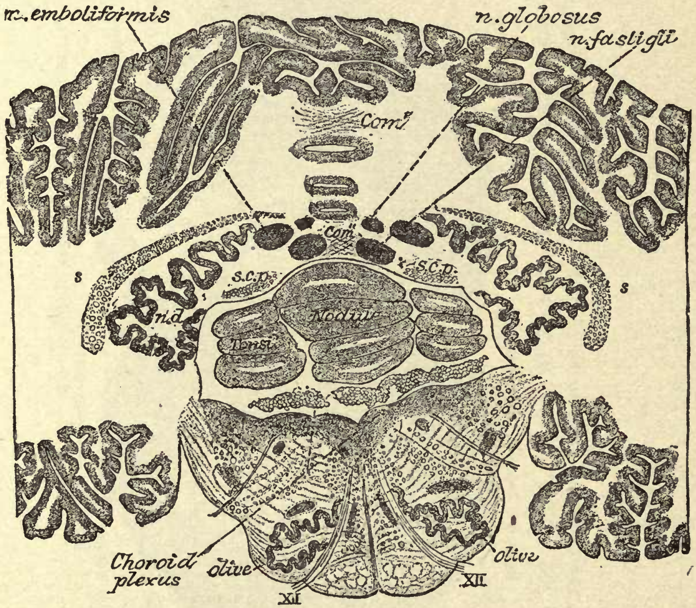


Fig. 123.—Section across the cerebellum and medulla oblongata showing the position of the nuclei in the medullary centre of the cerebellum. (Quain.)
n. d., nucleus dentatus cerebelli; *s,* band of fibres derived from restiform body, partly covering the dentate nucleus; *s. c. p.,* commencement of superior cerebellar peduncle; *com', com"*, commissural fibres crossing in the median white matter.

sisting largely of fibers making up the *superior peduncles of the cerebellum.*

The Tegmentum — Like the formatio reticularis the tegmentum consists of many interlocking fibers, definite bundles of which belong to the superior cerebellar peduncles. It also contains many

scattered nerve cells which form relay stations for some fibres coming from higher and lower levels.

The New Tracts of White Fibers.—The important nuclei of the brain stem, the medulla and midbrain, and cerebellum, have now been mentioned. It remains to describe the tracts of fibres which connect them and connect different levels. It will be convenient to start with the various tracts of white matter found in the spinal cord, though it must always be kept in mind that these tracts which carry impulses in a descending direction are being

Fig. 125.—Diagram showing the connections [illegible]

traced in a direction opposite to that in which they grow and [illegible] toward the region of the nerve cells of which they are composed.

Deep Arcuate Fibers.—We may start first with the posterior spinal columns, the columns of Goll and Burdach, carrying sensations of muscular sense, pressure, touch, and the coordination which result. These may be traced to their endings around the cells of the nucleus gracilis and cuneatus. From these nuclei other fibres are given off which pass forward, arching ventrally through the lower half of the medulla, to decussate in the middle line with similar fibres of the opposite side. These fibres are called the deep arcuate fibres. They then turn upward along the middle line, lying close to the middle line and confined to that portion of the fillet of the pons Varolii which adjoins the [illegible] as they pass up-

scattered nerve cells which form relay stations for some fibers coming from higher and lower levels.

The New Tracts of White Fibers — The important nuclei of the brain stem, the medulla and mid-brain, and cerebellum, have now been mentioned. It remains to describe the *tracts of white fibers connecting them and passing through them.* It will be convenient to start with the various tracts of white matter found in the spinal cord, though it must always be kept in mind that those tracts which carry impulses in a descending direction are being

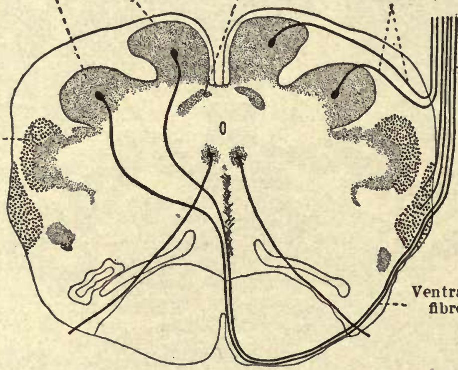


Fig. 124.—Diagram showing the composition of the cerebellar portions of the internal and external arcuate fibres. (Morris.)

tracted in a direction opposite to that in which they grow and functionate, and toward the origin of the axis cylinders of which they are composed.

Deep Arcuate Fibers — We may start first with the posterior spinal columns, the column of Burdach and Goll, carrying sensations of muscular sense — muscular tone and reflex coördination, which reach consciousness. These may be traced to their endings around the cells in the nucleus cuneatus and gracilis. From these nuclei other fibers are given off which pass inward and ventrally through the lower half of the medulla to decussate in the middle line with similar fibers of the opposite side. These fibers are called the *deep arcuate fibers.* They turn upward after decussation, lying close to the middle line and dorsal to that portion of the fibers of the pons Varolii which surrounds the pyramids as they pass up-

wards. They form a well-marked bundle in this situation called the *mesial fillet.* (Figs. 124–125 and 105 to 119.)

The mesial fillet may be traced upwards through the mid-brain where it occupies a more lateral position. Above the pons Varolii it leaves the middle line beneath the superior peduncle of the cerebellum, and at higher levels is lateral to the decussation of the superior peduncles. The mesial fillet terminates in the superior corpora quadrigemina, in the external geniculate bodies and in the optic thalami.

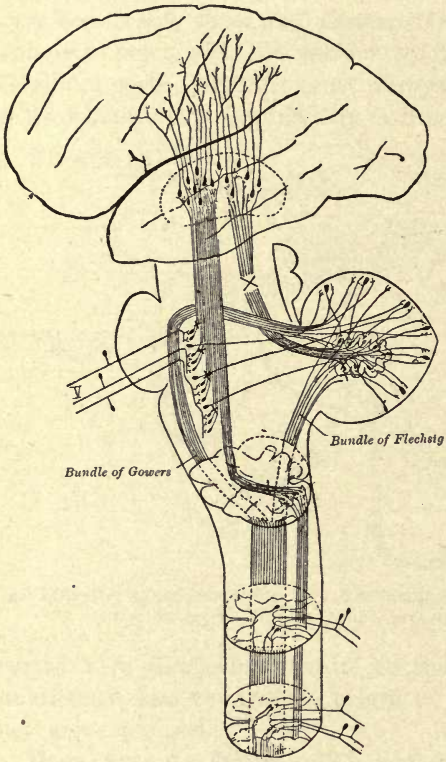


Fig. 125.—Diagram of the spino-cerebellar, bulbo-tegmental, cerebello-tegmental, ponto-tegmental, and ponto-cerebellar tracts. (Quain.)

Superficial Arcuate Fibers — A second set of fibers are given off from the nuclei cuneatus and gracilis, passing externally and ventrically instead of internally. These are the *superficial arcuate fibers* which pass over the tubercle of Rolando, over the upper portion of the olivary prominence, over the pyramids, over the opposite olive and tubercle of Rolando, to join the corpus restiforme of the opposite side. A number of the axons, particularly those springing from a *little accessory cuneate nucleus* on the lateral surface of the main nucleus, join the restiform body of the same side. As the restiform body forms the inferior peduncle of the cerebellum the ultimate termination of these fibers is to the gray matter of this portion of the cerebellum. They run directly to the cortex particularly of the vermis. (Fig. 124.)

The Termination of the Direct and Crossed Cerebellar Tracts. — Two more tracts in the spinal cord deserve a mention of some sort here and [illegible] consideration. They are the direct cerebellar tract and the ventral cerebellar tract. The former arising [illegible] which do not reach consciousness. Their cells [illegible] in the cells of Clarke's column, and they pass directly into the [illegible] and thus to the cerebellum. The [illegible] carries [illegible] which [illegible] on our [illegible]. The fibers of this tract travel upward through the [illegible] of the medulla oblongata [illegible] in the upper part of the pons after [illegible] tract and the [illegible] of the [illegible] tract. The [illegible] of that tract [illegible] which [illegible] the [illegible] by [illegible] directly [illegible] the upper [illegible] of the [illegible], passing with them to the cerebellum. [illegible]

The Spino-thalamic Fibers. — [illegible] of the antero-lateral column, the [illegible] sensations of pain, of heat and cold, and of touch and pressure. These fibers [illegible] the [illegible] and [illegible] of it. The [illegible] join the medial fillet and end with the [illegible] in the optic thalamus. As most [illegible] within the medulla and pons, [illegible] are found at these [illegible] (Fig. [illegible]).

The Connections of The Olive. — The olive or olivary nucleus [illegible] connected by [illegible] with the cerebellum [illegible] with the [illegible] of the same side. Most of the fibers, however, which are associated with the olivary nuclei, pass across the middle line to [illegible] the opposite olive and into the opposite [illegible]. [illegible] the olivary bodies [illegible] at least [illegible] with [illegible] of the opposite olive. It is possible that [illegible] of the [illegible] fibers [illegible] as [illegible] fibers originating in the olivary nucleus [illegible] down into the cord, and after being joined with [illegible] fibers [illegible] help to form [illegible] of Helweg. This tract [illegible], but it has been

The Termination of the Direct and Crossed Cerebellar Tracts — Two more tracts in the spinal cord convey sensations of muscular tone and muscular coördination. They are the *direct cerebellar tract* and the *anterior cerebellar tract.* The former convey the uncrossed muscular sensations which do not reach consciousness. Their axons originate in the cells of Clark's column and they pass directly into the corpus restiforme and then to the cerebellum. The antero-lateral cerebellar tract carries crossed muscular sensations which do not reach consciousness. The fibers of this tract travel upward through the formatio reticularis of the medulla oblongata, representing the only longitudinal spinal fibers in the upper part of the pons after the removal of direct cerebellar tracts and the posterior columns, with the exception of the pyramidal tracts. That portion of this tract, the posterior portion, which conveys muscular sensations, leaves the medulla by bending directly dorsally to join the superior peduncles of the cerebellum, passing with them to the cerebellum. (Figs. 124 and 125.)

The Spino-thalamic Fibers — Other bundles of the antero-lateral column, the spino-thalamic fibers, convey sensations of pain, of heat and cold, and of touch and pressure. These fibers form the column of Gowers internal to the crossed cerebellar tract and a bundle anterior to it. The two sets of fibers join the medial fillet and end with this bundle in the optic thalamus. As new masses of gray matter than those represented in the cord develop within the medulla and mid-brain, so also new tracts of fibers are found in these portions of the brain. (Fig. 125.)

The Connections of the Olive — The *inferior olivary nuclei* are directly connected by some fibers with the corpus restiforme and hence with the cerebellum of the same side. Most of the fibers, however, which are associated with the olivary nuclei, pass across the middle line through the opposite olive and into the opposite corpus restiforme. These fibers are axis cylinders of the olivary bodies — at least, ablation of one cerebellar hemisphere will cause atrophy of the opposite olive. It is possible that some of the olivo-cerebellar fibers may be efferent from the cerebellum, as some fibers originating in the olivary nucleus pass directly down into the cord, and after being joined with other fibers from the optic thalamus help to form the *thalamic or olivo-spinal tract of Helweg.* This tract then is a descending tract, but it has been

convenient to describe it with the other connections of the olivary nucleus. (Fig. 204.)

The Various Fibers Constituting the Corpus Restiforme, or Inferior Peduncle of the Cerebellum.—Before describing other [illegible] one other important connection to the [illegible] must be described. Some of the fibers of the vestibular branch of the eighth nerve, which are connected by collaterals with the nuclei of Monakow and Deiters, form a bundle known as the [illegible] body. The inferior peduncle or restiform body also contains fibers from the nuclei of the glossopharyngeal nerve and probably those running directly from the nuclei of Burdach and Goll. This bundle joins with the arcuate fibers and passes into the [illegible] and inferior peduncle. The following [illegible] therefore run in the restiform:

1. Fibers [illegible] the [illegible] tract of the [illegible] and [illegible] in the dorsal spinocerebellar tract.

2. Fibers from the dorsal [illegible] of the [illegible] of the same and opposite side.

3. Internal and external arcuate fibers from the olivary nucleus.

4. From the vestibular nerve, the [illegible] and [illegible] Deiters' nucleus, which have run directly to the cortex of the cerebellum, [illegible] the [illegible] of the [illegible].

The Middle Peduncle of the Cerebellum, or the Pons Varolii.—The [illegible] of cerebral hemispheres [illegible] most of their fibers from the [illegible]. The pons Varolii is largely composed of fibers which are chiefly transverse and run from one cerebellar hemisphere to the other. A large number of these enter the [illegible] are [illegible] of the [illegible] fibers and [illegible] the [illegible]. Many [illegible] pass between the frontal and temporal lobes and the [illegible] of the opposite side. It is [illegible] in the [illegible] that one connection between the cerebral cortex and the cerebellum is [illegible].

The Afferent Tracts to the Cerebellum in the Superior Peduncle.—Two other afferent tracts arise and are [illegible]. They have been previously mentioned. [illegible] the cord in the lateral portion [illegible] column, [illegible] the [illegible]

convenient to describe it with the other connections of the olivary nucleus. (Fig. 98.)

The Various Fibers Constituting the Corpus Restiforme, or Inferior Peduncle of the Cerebellum — Before describing other descending tracts, one other important connection to the restiform body remains to be described. Some of the fibers of the vestibular branch of the eighth nerve, which are connected by collaterals with the nuclei of Bechterew and Deiters, form a bundle known as the *internal restiform body.* The internal restiform body also contains fibers from the nuclei of the glossopharyngeal nerve and probably fibers running directly from the nuclei of Bechterew and Deiters. This bundle joins with the arcuate fibers and passes into the corpus restiforme and *inferior peduncle.* The following bundles of nerve fibers, therefore, run to the cerebellum.

1. Fibers originating in Clark's column of cells, homolateral and ascending in the direct cerebellar tract.

2. Fibers from the dorsal nuclei of the posterior columns of the same and opposite side.

3. Internal and superficial arcuate fibers from the olivary bodies.

4. From the vestibular nerve, the glossopharyngeal nerve and Deiters nucleus. All these fibers run directly to the cortex of the cerebellum, particularly the cortex of the vermis.

The Middle Peduncle of the Cerebellum, or the Pons Varolii — The cortex of cerebellar hemispheres receives most of its afferent fibers from the middle peduncle. The *pons Varolii* is largely composed of fibers which are only commissural and run from one cerebral hemisphere to the other. A large number of fibers entering the middle peduncle are axis cylinders of cells in the *formatio reticularis;* others are efferent and end around cells in the formatio reticularis. Many fibers of the crura cerebri pass between the frontal and temporal lobes, and the formatio reticularis of the opposite side. It is therefore in the formatio reticularis that one connection between the cerebral cortex and the cerebellum is effected.

The Afferent Tracts to the Cerebellum in the Superior Peduncle — Two other afferent tracts enter the cerebellum. They have been previously mentioned. One ascends from the cord in the lateral part of the antero-lateral column, conducting the crossed

muscle-like muscular sensations and passes into the cerebellum by the superior peduncle. The second comes from cells of the superior corpora quadrigemina and passes into the cerebellum also by the superior peduncles.

Inasmuch as the superior corpora quadrigemina receive the fibres of the optic nerve, this tract gives the means of association [illegible] important for purposes of coordination between the sense of vision and the cerebellar centres, an association much used in many muscular movements, few of which are not guided by sense of vision. So much for the afferent tracts of the cerebellum. The efferent fibres to the cells of the [illegible] contained in the middle peduncle, have been mentioned.

The Efferent Tracts from the Cerebellum. — Efferent fibres from the cerebellum leave from the cells lying in the nucleus dentatum, nucleus globosus and emboliformis. No efferent cerebellar fibres leave the cortex. A large mass of these leave the nucleus dentatus and pass by the superior peduncle to the red nucleus and [illegible] region of opposite side. A certain number of these pass also from the [illegible] to the [illegible] of the same side. [illegible] and but important tracts run between the [illegible] nuclei and the nucleus of Deiters and Bechterew. From these nuclei tracts run down to the different levels of the spinal cord in the antero-lateral column constituting the vestibulo-spinal column. It is doubtless in part through this tract that the impulses of equilibration are capable of affecting the motor apparatus of the spinal cord, passing by way of the vestibular nerve first to the cerebellum where they become [illegible] and influence [illegible] muscular adjustments by association with other impulses within this large centre of coordination where all impulses having to do with muscular [illegible] meet.

The Trapezium and Lateral Fillet (see Figs. 164 and 165). — Two other tracts of white matter through the mid brain and medulla are yet to be considered. One of these connects the nuclei of the auditory nerve with the inferior corpora quadrigemina. From both divisions of the nuclei of the auditory nerve, the dorsal and ventral, auditory nerve fibres pass internally to decussate with similar fibres of the opposite side (Figs. 161 to 164).

The decussating tract is called the trapezium and forms a dis-

conscious muscular sensations and passes into the cerebellum by the superior peduncle. The *second arises in cells* of the superior corpora quadrigemina and passes into the cerebellum also by the superior peduncles.

Inasmuch as the superior corpora quadrigemina receive the fibers of the optic nerve, this tract must transmit association impulses important for muscular coördination between the sense of vision and the cerebellar centers, an association much used in many muscular movements, few of which are not guided by sense of vision. So much for the afferent tracts of the cerebellum. The efferent fibers to the cells of the formatio reticularis, contained in the middle peduncle, have been mentioned.

The Efferent Tracts from the Cerebellum — All efferent fibers from the cerebellum leave from the central nuclei, the nucleus dentatum, fastigii, globosus and emboliformis. No efferent cerebellar fibers leave the cortex. A large mass of fibers leave the nucleus dentatum and pass by the superior peduncle to the red nucleus and subthalamic region of opposite side. A certain number of fibers pass also from the central nuclei to the corpora quadrigemina of the same side. No fibers pass directly to the spinal cord but important tracts run between the central nuclei and the nucleus of Bechterew and Deiters. From these nuclei large tracts run down to the different levels of the spinal cord in the antero-lateral column constituting the vestibulo-spinal column. It is doubtless in part through this tract that the impulses of equilibrium are capable of affecting the motor apparatus of the spinal cord, passing by way of the vestibular nerve, first to the cerebellum where they become modified into impulses permitting finer muscular adjustments by association with other impulses within this large center of coördination where all impulses having to do with muscular contraction meet.

The Trapezium and Lateral Fillet (see Figs. 102 and 126) — Two other tracts of white matter through the mid-brain and medulla are yet to be considered. One of these connects the nuclei of the auditory nerve with the inferior corpora quadrigemina. From both divisions of the nuclei of the auditory nerve, the dorsal and ventral nucleus, nerve fibers pass internally to decussate with similar fibers of the opposite side (Figs. 105 to 116.)

This decussating tract is called the *trapezium* and forms a defi-

nite structure in the medulla. The trapezium is situated just dorsal to the formatio reticularis. It is joined by nerve fibers from the superior olive and by the fibers of the striæ acusticæ

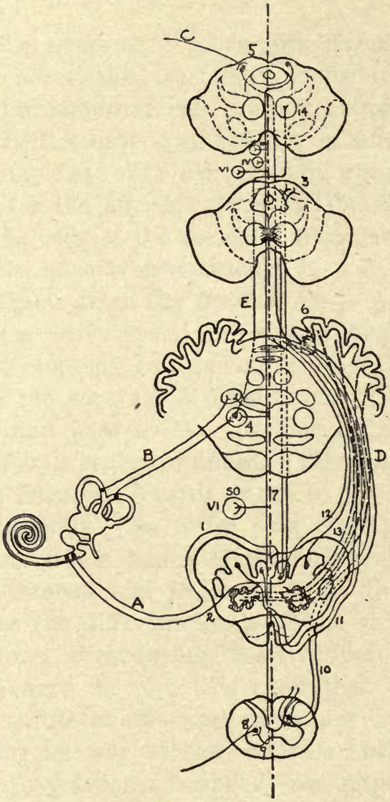


Fig. 126.

A. Auditory fibres passing by way of the stria acustica, 1, and the trapezium, 2, and the lateral fillet to the inferior corpus quadrigeminum, 3.

B. Vestibular fibres after making connections through the medulla passing to the dentate nucleus, 4.

C. Optic fibres passing to the superior corpus quadrigeminum, 5, from which fibres run to the cerebellar cortex, 6, and posterior longitudinal bundle, 7, which in turn establishes connections with the III and IV nucleus and the VIth and the anterior horn cells, 8, by means of the antero-lateral column, 9.

D. Afferent cerebellar fibres composed of the posterior cerebellar tract, 10, to the cerebellar cortex, 6, and the superficial external arcuate fibres, 11, to the cortex of the vermis. The direct cuneate cerebellar fibres, 12, and the olivo-cerebellar fibres, 13.

E. Efferent cerebellar fibres to the red nucleus, 14, from the dentate nucleus, 4.

after these have crossed at the floor of the medulla and fibers from the auditory nucleus. All these fibers become collected into a bundle which passes upwards through the mid brain where they form the *lateral fillet*. It lies to the outer side of the superior cerebellar peduncle. It eventually passes around the peduncle on its outer side and in the anterior end to the inferior corpora quadrigemina in which the fibers of the lateral fillet end. (Figs. 125, 126.) The inferior corpora quadrigemina form substations for auditory sensations.

The Posterior Longitudinal Bundle.—The other white tract through the mid brain and pons is the posterior longitudinal bundle. It is an important bundle seen in all sections through the pons and mid brain, and continues throughout the spinal cord in the anterolateral columns as the tract of Marchi. (Figs. 122 and 125-126.)

The posterior longitudinal bundle is a well-defined tract existing near the middle line just dorsal to the tegmentum of the mid brain and of the formatio reticularis in the medulla oblongata. It connects the nuclei of the various cranial nerves with each other; it contains therefore fibers which run in both directions.

Summary of the Various Substations.—We have now considered the principal new masses of gray matter which have been added to the cerebrospinal axis in the hind and middle brain.

We have also followed the connections of these nuclei, and the principal tracts connecting these nuclei and carrying impulses from them and from the spinal cord up to them. They may be looked upon as regional substations of impulses, standing next to the cerebrum in the receipt or transmission of impulses passing between the cerebrum and the lower portions of the nervous system. These principal substations are engaged at different levels for various white tracts in the cerebrospinal axis. In the case of the pyramidal tracts the principal substation between the cerebrum and the spinal cord is in the spinal cord itself. In the case of fibers also running in the same column the principal substation is in the formatio reticularis. In other tracts it is in the red nucleus and the anterior quadrigemina, while in the case of still others the principal station is in the base of the fore brain itself, namely in the optic thalami.

The New Masses of Gray Matter Belonging to the Fore Brain.—It now remains to describe the new masses of gray matter be-

after these have crossed on the floor of the medulla and fibers from the auditory nucleus. All these fibers become collected into a bundle which passes upwards through the mid-brain where they form the *lateral fillet.* It lies to the outer side of the superior cerebellar peduncle. It virtually passes around the peduncle on its outer side and in this manner gains the inferior corpora quadrigemina in which the fibers of the lateral fillet end. (Figs. 105–116.) The inferior corpora quadrigemina form substations for auditory sensations.

The Posterior Longitudinal Bundle — The other white tract through the mid-brain and pons is the *posterior longitudinal bundle.* It is an important bundle seen in all sections through the pons and mid-brain, and continued throughout the spinal cord in the antero-lateral column as the tract of Marie. (Figs. 126 and 105–116.)

The posterior longitudinal bundle is a well-defined tract running near the middle line just dorsal to the tegmentum in the mid-brain, and to the formatio reticularis in the medulla oblongata. It connects the nuclei of the various cranial nerves with each other and contains, therefore, fibers which run in both directions.

Summary of the Various Substations — We have now considered the principal new masses of gray matter which have been added to the cerebrospinal axis in the hind and middle brain.

We have also followed the connections of these nuclei, and the principal tracts connecting these nuclei and carrying impulses from them and from the spinal cord up to them: they may be termed the terminal substation of impulses, standing next to the cerebrum in the receipt or transmission of impulses passing between the cerebrum and the lower portions of the nervous system. These terminal substations are situated at different levels for various white tracts in the cerebrospinal axis. In the case of the pyramidal tracts the terminal substation between the cerebrum and the spinal cord is in the spinal cord itself. In the case of other fibers also running in the crura cerebri the terminal substation is in the formatio reticularis. For other tracts it is in the red nucleus and the corpora quadrigemina, while in the case of still others the terminal station is in the base of the fore-brain itself, namely in the optic thalami.

The New Masses of Gray Matter Belonging to the Fore-Brain — It now remains to describe the new masses of gray matter be-

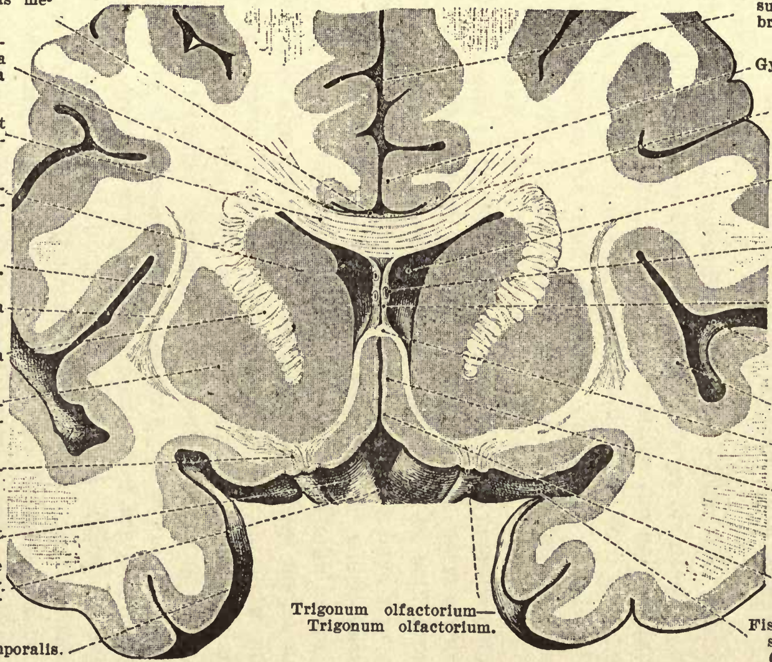


Fig. 127.—Coronal section passing in front of the anterior commissure of the cerebrum and through the anterior extremities of the caudate and lenticular nuclei. Posterior surface of anterior segment. A view is obtained of the anterior walls of the anterior horns of the lateral ventricle. (Toldt.)

[illegible] to the [illegible] arising from what we have termed the [illegible] vesicle, and those parts of connection between them and the so-called lateral ventricles placed between the cerebrum and the lower portions of the fore-brain [illegible].

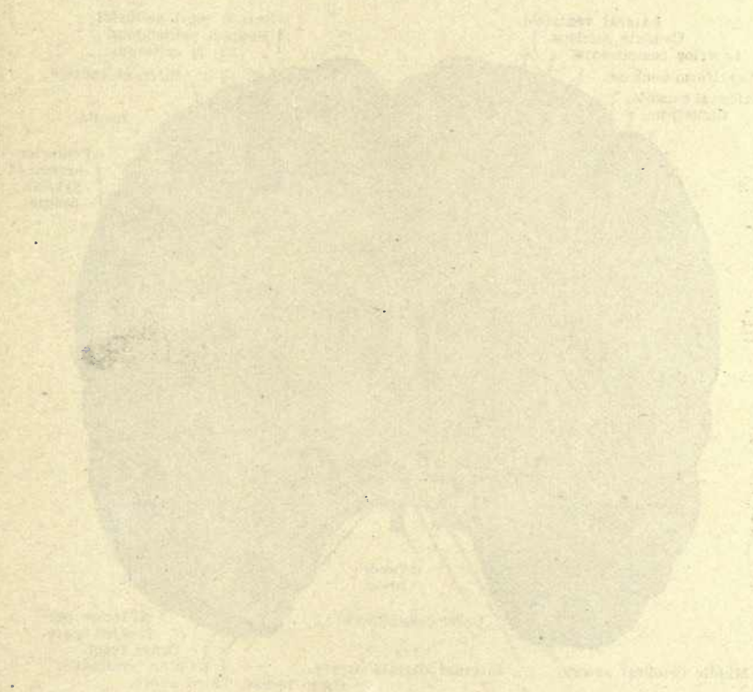


FIG. 186.—View from the front of a section of an adult brain made [illegible] the frontal lobe [illegible] the lateral ventricles. [illegible] Sylvian fissure [illegible]

The majority of pure masses of gray matter of the fore-brain have already been described. They include the cerebral cortex itself and the walls of the third ventricle, the structures appearing in the lateral ventricles, the caudate nucleus and the optic thalami themselves.

longing to the cerebrum arising from what we have termed the precerebral vesicles, and those paths of connection between them and the so-called terminal substations placed between the cerebrum and the lower portions of the cerebrospinal axis.

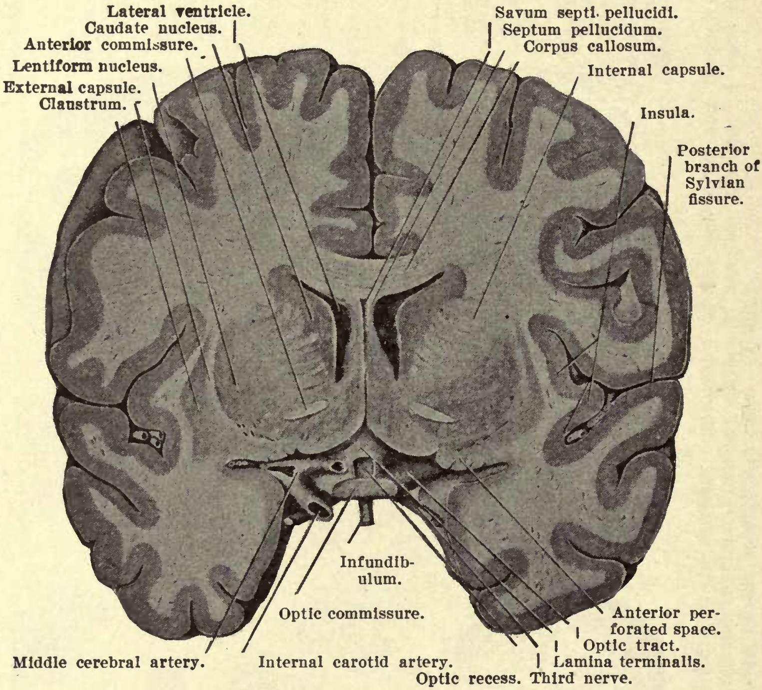


Fig. 128.—View from the front of a coronal section of an adult brain made two and a half inches behind the frontal pole and nearly one inch behind the temporal pole and about half an inch posterior to the anterior end of the lateral ventricles. Five-sixths. (Quain.)

The vallecula Sylvii is seen on each side external to the optic commissure; on the right side of the brain the internal carotid artery is shown dividing in this space into the anterior and middle cerebral arteries.

The majority of new masses of gray matter of the fore-brain have already been described. They include the cerebral cortex itself and the walls of the third ventricle, the structures appearing in the lateral ventricles, the caudate nucleus and the optic thalami themselves.

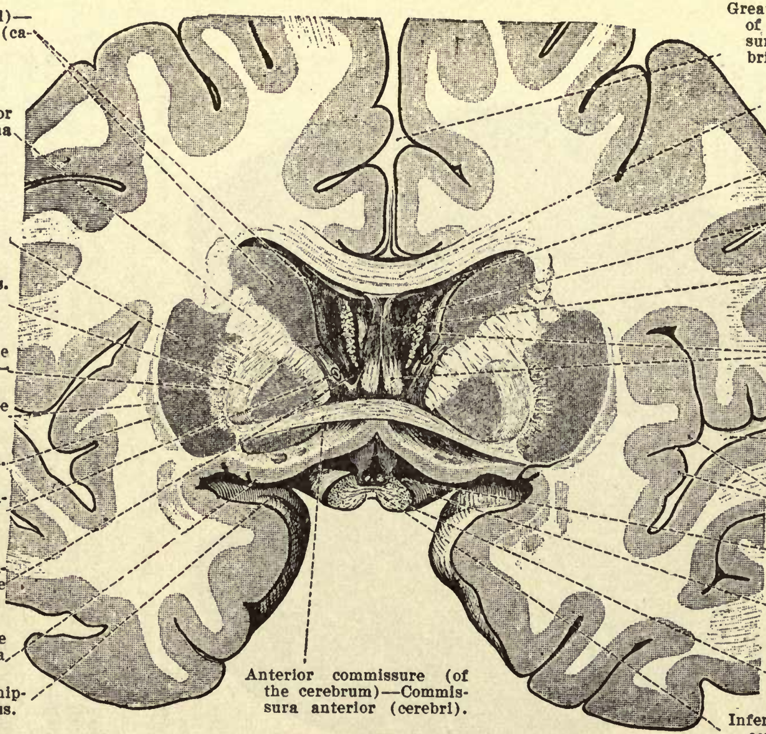


Fig. 129.—Coronal section passing through the optic commissure or chiasma and through the anterior commissure of the cerebrum. Anterior surface of posterior segment. A view is obtained into the third ventricle from before. (Toldt.)

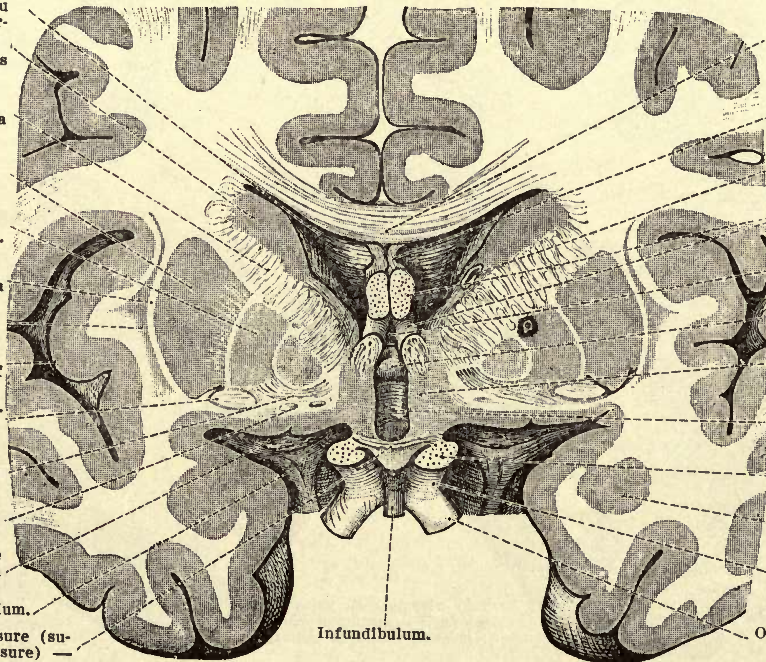


Fig. 130.—Coronal section behind the optic commissure or chiasma, passing through the infundibulum and the anterior pillars of the fornix or columnæ fornicis. Posterior surface of anterior segment. A view is obtained of the interior of the anterior horns of the lateral ventricle and the anterior wall of the third ventricle is displayed. (Toldt.)

The Internal Capsule.—Internal to the optic thalamus is the third ventricle, the lateral walls of which are formed by the optic thalami. A small portion of the optic thalami appears in the lateral ventricle. Most of its external surface is surrounded by a white capsule-like layer of white fibers termed the internal capsule, the great pathway of all afferent and efferent impulses to and from the cerebrum.

The internal capsule is formed of all those nerve fibers which pass from various portions of the cerebrum to the crura cerebri, and in part of fibers emerging from the optic thalamus to be dis-

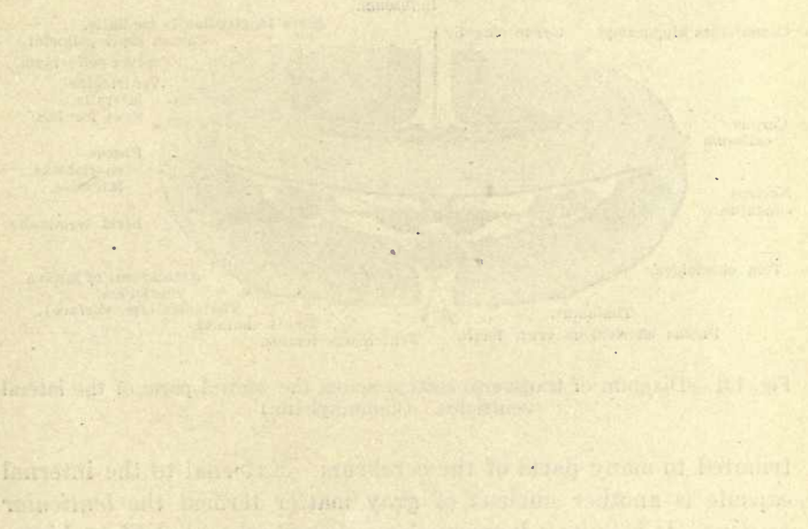


Fig. 131.—Diagram of transverse section across the central part of the lateral ventricles. (Sobotta-McMurrich.)

tributed to motor parts of the cerebrum. External to the internal capsule is another nucleus of gray matter termed the lenticular nucleus. It is quite a large nucleus, shaped somewhat like a biconvex lens on both transverse and horizontal section. It separates the internal capsule from another layer of white fibers termed the external capsule. Outside the external capsule is another nucleus of gray matter, thin on transverse section, termed the claustrum.

Classification of the Cerebral Nerve Tracts.—The tracts of white fibers of the cerebrum may be classed as nerve tracts connecting the brain with lower levels. They are afferent and efferent.

Nerve tracts connecting different portions of one cerebral hemisphere.

Tracts connecting two cerebral hemispheres.

The Afferent Tracts of the Cerebrum.—The Sensory cortical

The Internal Capsule — Internal to the optic thalami is the third ventricle, the lateral walls of which are formed by the optic thalami. A small portion of the optic thalami appears in the lateral ventricle. Most of its external surface is surrounded by thick, capsule-like layer of white fibers termed the *internal capsule,* the great pathway of all afferent and efferent impulses to and from the cerebrum.

The internal capsule is formed of all those nerve fibers which pass from various portions of the cerebrum in the crura cerebri, and in part of fibers emerging from the optic thalami to be dis-

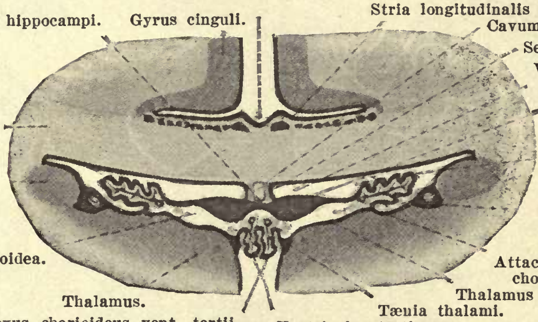


Fig. 131.—Diagram of transverse section across the central parts of the lateral ventricles. (Cunningham.)

tributed to many parts of the cerebrum. External to the internal capsule is another nucleus of gray matter termed the *lenticular nucleus.* It is quite a large nucleus, shaped somewhat like a biconvex lens on both transverse and horizontal section. It separates the internal capsule from another layer of white fibers termed the *external capsule.* Outside the external capsule is another nucleus of gray matter, thin on transverse section, termed the *claustrum.*

Classification of the Cerebral Nerve Tracts — The tracts of white fibers of the cerebrum may be classed as nerve tracts connecting the brain with lower levels. They are afferent and efferent.

Nerve tracts connecting different portions of one cerebral hemisphere.

Tracts connecting two cerebral hemispheres.

The Afferent Tracts of the Cerebrum — The *thalamo-cortical*

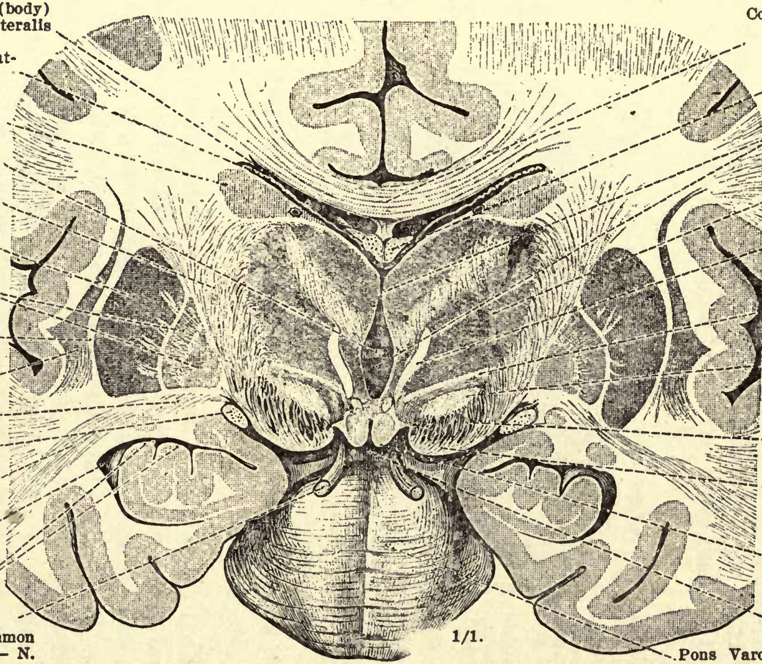


Fig. 132.—Coronal section in front of the pons, passing through the crura cerebri or cerebral peduncles and the corpora mammillaria *seu* albicantia. Anterior surface of posterior segment. The third ventricle is cut across, also the body of the descending horn of the lateral ventricle; the descending horn is divided close to its anterior extremity. (Toldt.)

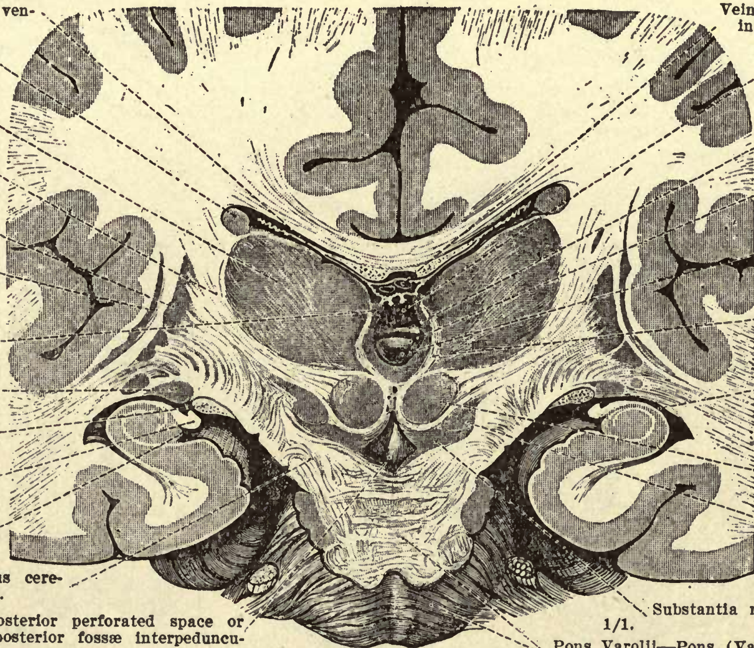


Fig. 133.—Coronal section, passing through the anterior portion of the pons varolii, the optic thalami, and the posterior extremity of the lenticular nucleus. Anterior surface of posterior segment. A view is obtained of the posterior wall of the third ventricle. The central portion or body and the middle, lateral, or descending horn of the lateral ventricle are cut across by the section. (Toldt.)

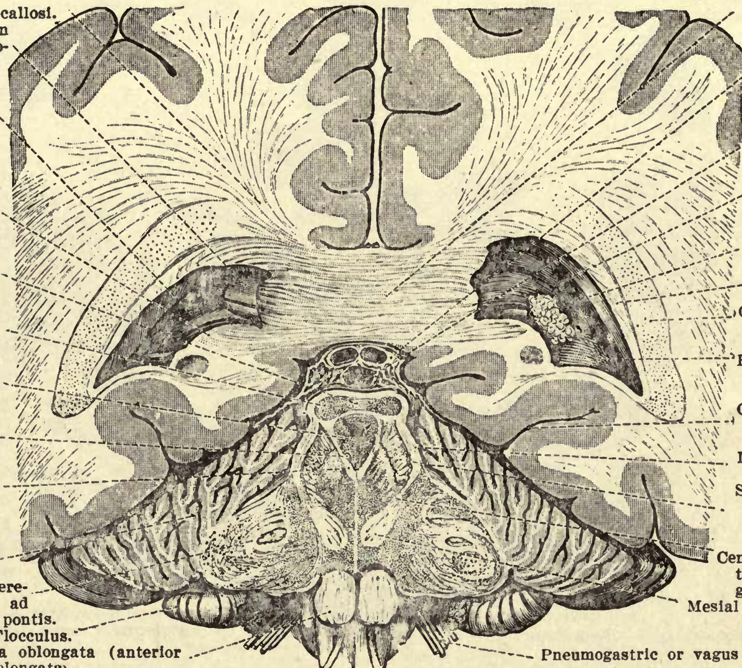


Fig. 134.—Coronal section, passing behind the pons varolii, through the upper extremities of the pyramids and through the splenium of the corpus callosum. Anterior surface of posterior segment. A view is obtained into the posterior horns of the lateral ventricles.

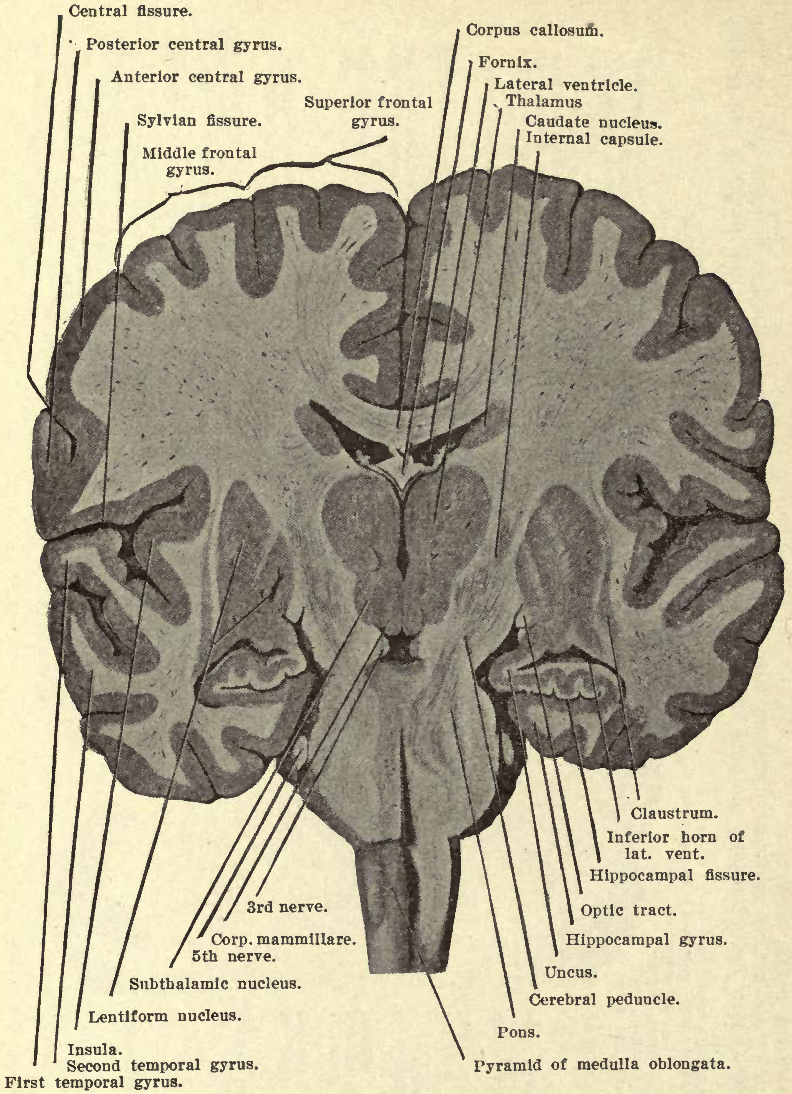


Fig. 135.—View from the front of a coronal section of an adult brain made three inches behind the frontal pole. Five-sixths.

tracts. From all parts of the optic thalami fibers stream out into the internal capsule to carry on the impulse arriving at the optic thalami to all parts of the cerebral cortex. Entering the internal

capsule these fibers may be divided into a frontal, parietal, occipital and temporal group.

The frontal fibers are contained in the anterior limb of the internal capsule and run to the frontal lobe. Some of the fibers pass to the lenticular nucleus and then after [illegible] on the [illegible] through the external capsule.

The parietal fibers arise from the lateral surface of the optic thalamus and pass to the parietal lobe through the middle portions of the internal capsule. The occipital fibers form radiations called the occipital radiations, and pass to the occipital lobe through the posterior portion of the internal capsule, coming chiefly from the pulvinar, or posterior tubercle of the optic thalamus and the external geniculate body.

The fibers coming from the under surface of the optic thalami pass under the lenticular nucleus to the temporal lobe and island of Reil. Some of these fibers, known as the auditory radiations, pass directly into the posterior portion of internal capsule from the internal geniculate body.

Functions of the Thalamo-cortical Fibers. — Of these various afferent fibers, those passing to the parietal lobe carry stimuli to the cortex the cutaneous and muscular sensations, reaching the optic thalamus through the fillet. Also among the fibers of the anterior or middle portions of the internal capsule are those carrying on the impulses reaching the red nucleus and optic thalamus by the superior cerebellar peduncles.

They must be considered as furnishing information regarding the fine adjustments in muscular coordination being produced by the cerebellum. The optic radiations carry visual impulses from the terminations of the optic nerve to the superior corpora quadrigemina. By other fibers between the occipital cortex and these same [illegible] impulses may pass from the cortex to the superior corpora quadrigemina and thence as efferent impulses to the [illegible]. Through the auditory radiations to the temporal lobes are transmitted impulses from the inferior corpora quadrigemina and internal geniculate body, which latter receive the termination of the lateral fillet directly from the auditory nucleus.

Other fibers pass between the optic thalamus and the cerebral cortex by way of the corona radiata. The larger portion of the afferent fibers of this body come from the optic thalami. Other

capsule these fibers may be divided into a *frontal, parietal, occipital* and *temporal* group.

The *frontal fibers* are contained in the anterior limit of the internal capsule and run to the frontal lobe. Some of the fibers pass to the lenticular nucleus and then other axons carry on the impulses through the external capsule.

The *parietal fibers* issue from the lateral surface of the optic thalami and pass to the parietal lobe through the middle portions of the internal capsule. The *occipital fibers* form radiations called the occipital radiations, and pass to the occipital lobe through the posterior portion of the internal capsule, coming chiefly from the pulvinar or posterior tubercle of the optic thalamus and the external geniculate body.

The fibers issuing from the under surface of the optic thalami pass under the lenticular nucleus to the *temporal lobe* and island of Reil. Some of these fibers, known as the auditory radiations, pass directly into the posterior portion of internal capsule from the internal geniculate body.

Functions of the Thalamo-cortical Fibers — Of these various afferent fibers, those passing to the parietal lobes carry onward to the cortex the *cutaneous* and possibly *muscular sensations,* reaching the optic thalami through the mesial fillet. Also among the fibers of the anterior or middle portions of the internal capsule are those carrying on the impulses reaching the *red nucleus* and *optic thalami* by the superior cerebellar peduncles.

They must be considered as furnishing information regarding the fine adjustments in muscular coördination being produced by the cerebellum. The optic radiations carry visual impulse from the terminations of the optic nerve in the superior corpora quadrigemina. By other fibers between the occipital cortex and these basal nuclei impulses may pass from the cortex to the superior corpora quadrigemina and thence as afferent impulses to the cerebellum. Through the auditory radiations to the temporal lobes are transmitted impulses from the inferior corpora quadrigemina and internal geniculate body, which nuclei receive the termination of the lateral fillet directly from the auditory nucleus.

Other fibers pass between the optic thalamus and the cerebral cortex by way of the *corpus striatum.* The larger portion of the afferent fibers of this body come from the optic thalami. Other

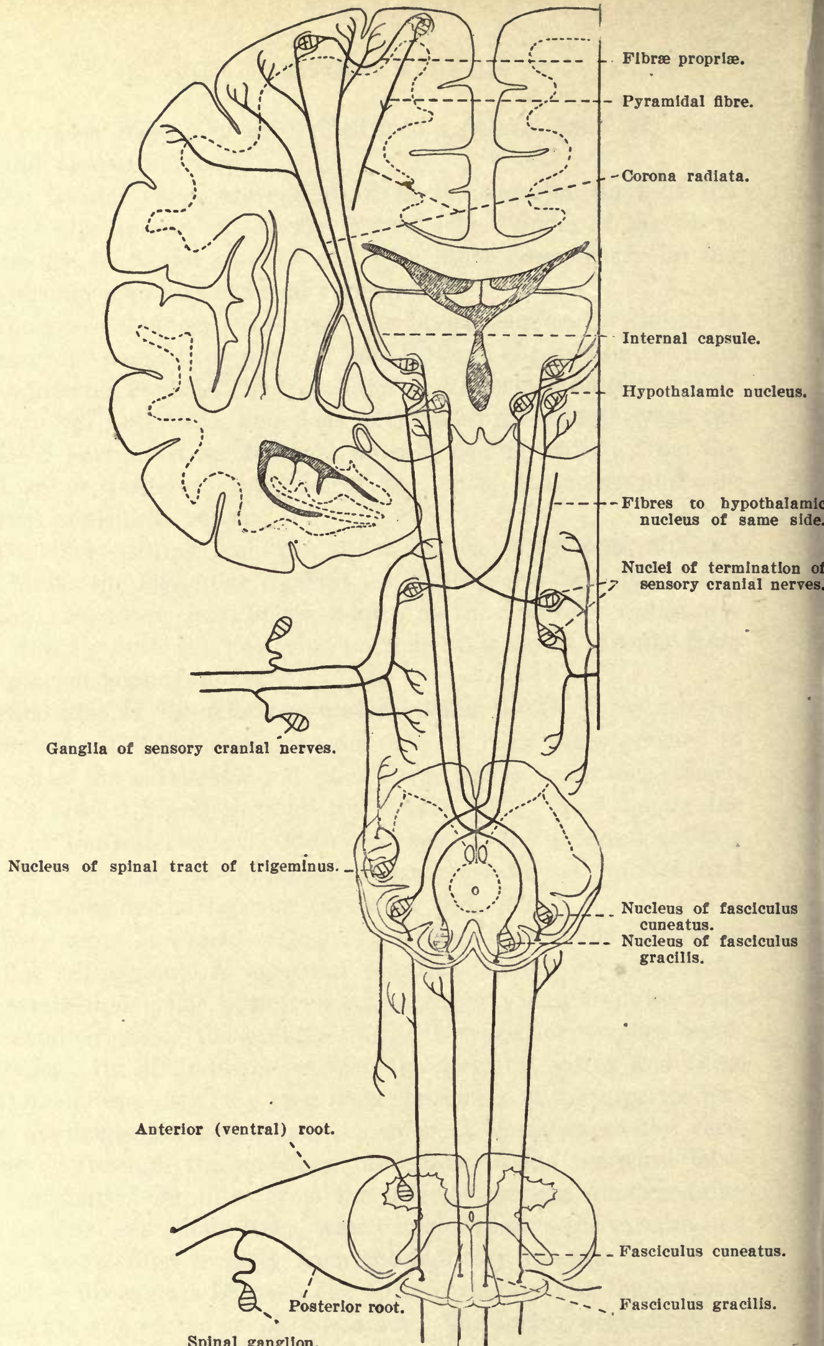


Fig. 136.—Scheme of ascending or spinocerebral conduction pathways. (Morris.)

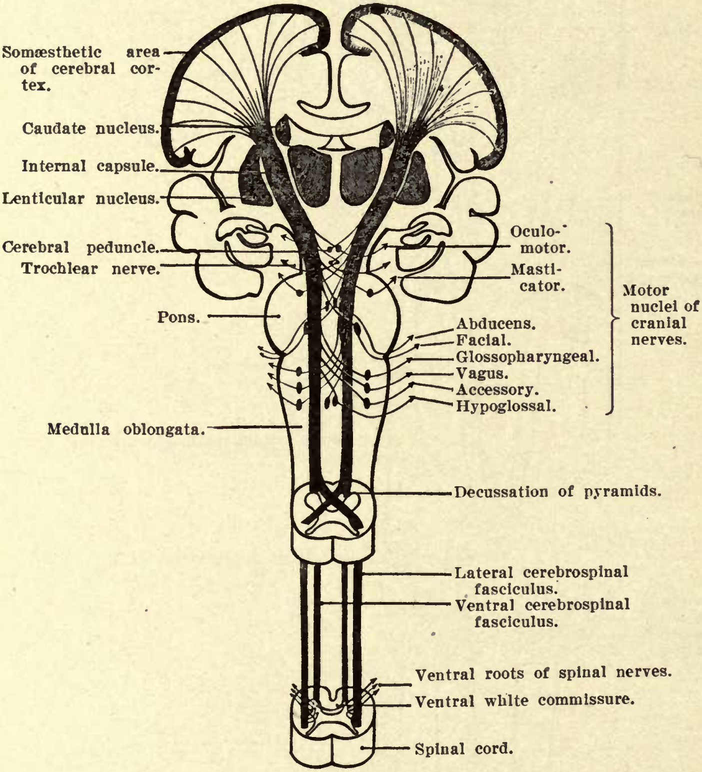


Fig. 137.—Scheme of descending cerebrospinal conduction pathways. (Morris.)

fibers arising in the corpus striatum pass to the dorsal part of the crista to the gray nuclei of the formatio reticularis.

Connections undoubtedly exist in both directions between the cortex cerebri and the nuclei of the corpus striatum. The chief nucleus of the corpus striatum is the caudate nucleus. The lenticular nucleus and claustrum come next in importance.

Pyramidal Tract.—(*Tractus cortico-spinalis; Fasciculi cerebro-spinales.*) The pyramidal tract originates as the cylindraxes of the cells in the ascending frontal convolution. The fibers pass downwards and inwards through the white matter of the hemisphere to the internal capsule. In this structure they occupy the middle two-fifths of the internal capsule. The internal capsule resembles a band of the junctions of the anterior and posterior two-thirds, with the concavity outwards, and surrounds the lenticular nucleus. Anterior to the lenticular nucleus the caudate nucleus lies internal to it and posterior to the bend the optic thalamus lies internal to it. The pyramidal fibers occupy the bend and the anterior two-thirds of the portion posterior to the bend. In this portion the fibers controlling the muscles of the head lie anteriorly, then the fibers belonging to the anterior extremity, the trunk and posterior extremity. The pyramidal fibers finally leave the internal capsule and enter the crusta or crura cerebri. These structures may be viewed as the stems of the brain. In the mid-brain they lie ventral to the rest of the mid-brain and diverge as they are traced upwards and forwards between the mid-brain and the cerebrum, to enter the latter by forming the internal capsule. The two crura thus fork to include between them as they enter the brain the two optic thalami. (Fig. 147.)

The tegmentum of the mid-brain, that is the dorsal portion, enters the cerebrum by passing directly into the optic thalami. In the crusta the pyramidal fibers form the middle two-fifths of that structure.

A small portion of the dorsal part of the external surface of the optic thalamus, above the diverging fibers of internal capsule, lies free in the beginning of the descending horn of the lateral ventricle.

Fronto-pontine Fibers.—In the anterior limb of the internal capsule other nerve fibers arising as the cylindraxes of the nerve cells in the frontal lobe of the brain pass down into the frontal

fibers arising in the corpus striatum pass in the dorsal part of the crusta to the nuclei pontis of the formatio reticularis.

Connections undoubtedly exist in both directions between the cortex cerebri and the nuclei of the corpus striatum. The chief nucleus of the corpus striatum is the caudate nucleus. The lenticular nucleus and claustrum form similar connections.

Pyramidal Tracts — *The efferent tracts from the Cerebrum* — The pyramidal tract originates as axis cylinders of the cells in the ascending frontal convolution. The fibers pass downwards and inwards through the white matter of the hemispheres to the internal capsule. In this structure they occupy the *middle two-fifths* on transverse section. The internal capsule presents a bend at the juncture of the anterior one-third and posterior two-thirds, with the concavity outwards, and surrounds the lenticular nucleus. Anterior to the bend the caudate nucleus lies internal to it and posterior to the bend the optic thalamus lies internal to it. The pyramidal fibers occupy the bend and the anterior two-thirds of the portion posterior to the bend. In this portion the fibers controlling the muscles of the head lie anteriorly, then the fibers belonging to the anterior extremity, the trunk and posterior extremity. The pyramidal fibers finally leave the internal capsule and enter the crusta or crura cerebri. These structures may be viewed as the stems of the brain. In the mid-brain they lie ventral to the rest of the mid-brain and diverge as they are traced upwards and forwards between the mid-brain and the cerebrum, to enter the latter by forming the internal capsule. The two crusta thus fork to inclose between them as they enter the brain the two optic thalami. (Fig. 137.)

The remainder of the mid-brain, that is the dorsal portion, enters the cerebrum by passing directly into the optic thalami. In the crusta the pyramidal fibers form the middle two-fifths of that structure.

A small portion of the upper part of the external surface of the optic thalami, above the diverging fibers of internal capsule, lies free in the beginning of the descending horn of the lateral ventricle.

Fronto-pontine Fibers — In the anterior limb of the internal capsule other nerve fibers, arising as axis cylinders of the nerve cells in the frontal lobes of the brain, pass down into the mesial

portion of the crusta and end around the scattered cells in the formatio reticularis.

Temporo-pontine Fibers.—Other efferent fibers from the external strata of the temporal lobes end reach the posterior limb of the internal capsule by passing under the lenticular nucleus. They then reach the external division of the crusta and end in the scattered cells of the pons.

Both the fronto-pontine and temporo-pontine fibers represent efferent fibers from the cerebrum and afferent to the cerebellum of the cerebro-cerebellar connections, being continued into the lateral hemispheres of the cerebellum by the transversely running middle peduncles. The afferent tract of this cerebro-cerebellar connection is from the cortex of cerebellum to the dentate nucleus, then by the superior peduncles to the red nucleus and optic thalami, and finally from the optic thalami to the cerebral cortex. Part of the thalamo-cortical fibers have already been described, those passing directly into the internal capsule and around the lenticular nucleus to the thalamic (frontal, thalamo-parietal) and the auditory and optic radiations.

Intra-Cerebral Association Tracts.—Short and long association fibers exist within the cerebrum. The short tracts pass in U-shaped loops between the various convolutions around the bottom of the sulci. The long tracts may be divided into longitudinal tracts and commissural tracts. The longitudinal tracts are:

Uncinate fasciculus.—Between the orbital convolutions of the frontal lobes and the front part of the temporal lobe, around the bottom of the fissure of Sylvius.

The cingulum.—Within the callosal gyrus and over the dorsum of the corpus callosum to the hippocampal gyrus and anterior part of temporal lobe. (Fig. 181.)

Superior longitudinal fasciculus.—Runs about the same course as the cingulum, connecting the frontal, parietal and occipital lobes.

Inferior longitudinal fasciculus.—External to the optic radiation between the temporal and occipital lobes.

Occipito-frontal fasciculus.—Runs close to caudate nucleus in outer walls of lateral ventricle.

The commissural fibers include:

(a) The great mass of cortical fibers running between the

portion of the crusta and end around the scattered cells in the formatio reticularis.

Temporo-pontine Fibers — Other efferent fibers from the cerebrum arise in the temporal lobes and reach the posterior limb of the internal capsule by passing under the lenticular nucleus. They then reach the external division of the crusta and end in the scattered cells of the pons.

Both the fronto-pontine and temporo-pontine fibers represent efferent tracts from the cerebrum and afferent to the cerebellum of the cerebro-cerebellar connections, being continued into the lateral hemispheres of the cerebellum by the transversely running middle peduncles. The return tract of this cerebro-cerebellar connection is from the cortex of cerebellum to the dentate nucleus, then by the superior peduncles to the red nucleus and optic thalami, and finally from the optic thalami to the cerebral cortex. Part of the thalamo-cortical fibers have already been described, those passing directly into the internal capsule and around the lenticular nucleus as the thalamo-frontal, thalamo-parietal and the auditory and optic radiations.

Intra-Cerebral Association Tracts — Short and long association tracts exist within the cerebrum. The *short* tracts pass in U-shaped loops between the various convolutions around the bottom of the sulci. The *long* tracts may be divided into longitudinal tracts and commissural tracts. The longitudinal tracts are:

Uncinate fasciculus — Between the orbital convolutions of the frontal lobes and the front part of the temporal lobes, around the bottom of the fissure of Sylvius.

The cingulum — From the *anterior perforated* space over the dorsum of the corpus striatum to the hippocampus major and anterior part of temporal lobe. (Fig. 138.)

Superior longitudinal fasciculus — Somewhat the same course as the cingulum, connecting the *frontal parietal and occipital lobes.*

Inferior longitudinal fasciculus — External to the optic radiation between the *temporal and occipital lobes.*

Occipito-frontal fasciculus — Runs close to caudate nucleus in outer walls of lateral ventricle.

The commissural fibers include:

(a) The great mass of cortical fibers running between the

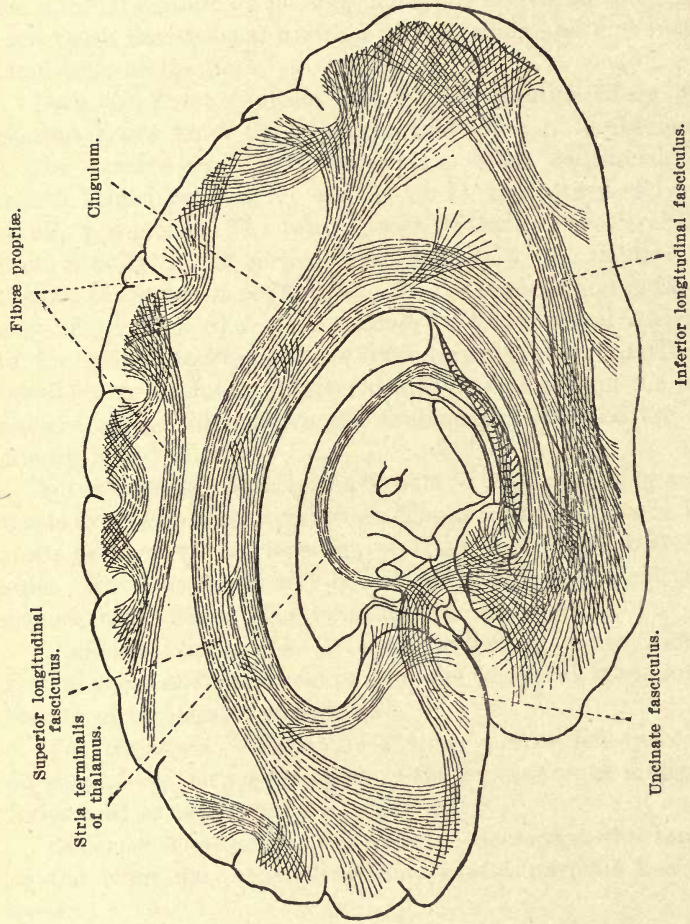


Fig. 138.—Schematic representation of certain of the association pathways of the cerebral hemisphere. (Morris.)

two hemispheres and constituting the major portion of the corpus callosum.

(b) The anterior commissure, connecting the two olfactory lobes and portions of the two temporal lobes.

(c) Middle commissure, between the optic thalami.

(d) The hippocampal commissure, a thin lamina between the diverging posterior pillars of the fornix, appearing on the under surface of the corpus callosum, connecting the two hippocampi majores.

FUNCTIONS AND DISTRIBUTION OF THE CRANIAL NERVES

Olfactory Nerves.— The olfactory or the bulb nerves are to be viewed as cerebral association tracts connecting the brain with a more distal portion of that same organ.

Anatomically they are different from the other cranial nerves. The olfactory nerve fibers are derived from cells situated upon the surface of the body embedded within the nasal mucous membrane. One process, the peripheral olfactory nerve, passes forward toward the surface to end in the olfactory end sense organ. The other process passes backward as a medullated nerve fiber through the cribriform plate to the olfactory bulb, where they terminate in a terminal arborization around the branches of another terminal arborization of the peripheral process of another nerve cell called a mitral cell.

It is the axons of the mitral cells which form the olfactory tracts. Each tract divides posteriorly into two roots, a mesial root ending in the anterior end of the callosal gyrus of the limbic lobe, and a lateral root, crossing the anterior perforated space to end in the uncinate extremity of the hippocampal gyrus. Between these two roots is a prominence, the olfactory tubercle.

Portions of the Brain Forming the Olfactory Mechanism.— The following portions of the brain serve as central nuclei and association centers of the olfactory apparatus.

(1) Olfactory bulb and tract.
(2) Anterior perforated space.
(3) Anterior portion of the uncinate gyrus.
(4) Septum lucidum.
(5) Hippocampal convolution.

two hemispheres and constituting the major portion of the corpus callosum.

(b) The anterior commissure, connecting the two olfactory lobes and portions of the two temporal lobes.

(c) Middle commissure, between the optic thalami.

(d) The hippocampal commissure, a thin lamina between the diverging posterior pillars of the fornix, appears on the under surface of the corpus callosum, connecting the two hippocampi majora.

FUNCTIONS AND CONNECTIONS OF THE CRANIAL NERVES

Olfactory Nerves — The olfactory as the optic nerves are to be viewed as cerebral associated tracts connecting the brain with a more distal portion of this same organ.

Anatomically they are different from the other cranial nerves.

The olfactory nerve fibers are derived from cells situated upon the surface of the body imbedded within the nasal mucous membrane. One process, the real olfactory nerve, passes forward toward the surface to end in the olfactory end sense organ. The other process passes backward as a medullated nerve fiber, through the cribriform plate to the olfactory bulb, where they terminate in a terminal arborization among the branches of another terminal arborization of the peripheral process of another nerve cell called a mitral cell.

It is the axons of the mitral cells which form the olfactory tracts. Each tract divides posteriorly into two roots, a mesial root ending in the anterior end of the callosal gyrus of the limbic lobe, and a lateral root, crossing the anterior perforated space to end in the uncinate extremity of the hippocampal gyrus. Between these two tracts is a prominence, the olfactory tubercle.

Portions of the Brain Forming the Olfactory Mechanism — The following portions of the brain serve as central nuclei and association tracts of the olfactory apparatus.

(1) Olfactory bulb and tract.
(2) Anterior perforated space.
(3) Anterior portion of the uncinate gyrus.
(4) Septum lucidum.
(5) Hippocampal convolution.

(6) Anterior commissure.
(7) Trigonum habenulæ.
(8) Fornix.
(9) Corpora mammillaria.
(10) The bundle of Vicq d'Azyr.
(11) Optic thalami.

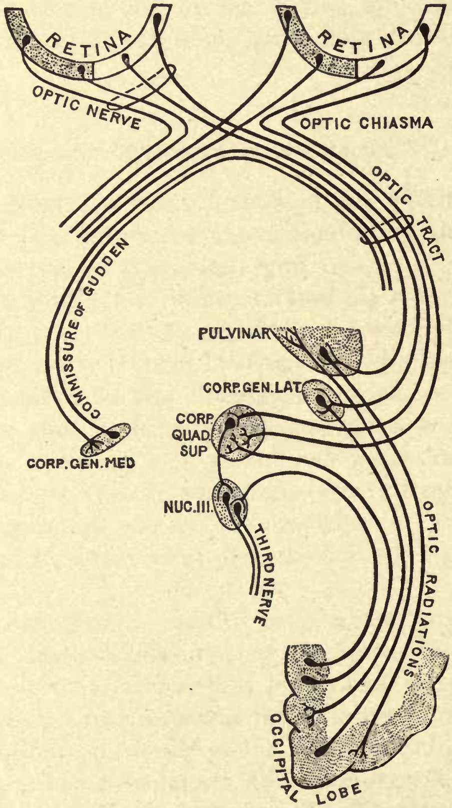


Fig. 139.—Diagram of the principal components of the optic apparatus. (Morris.)

The Optic Nerve — The real optic nerves are merely the short processes of nerve cells, situated within the retina and passing to the sensory epithelium of the retina. The central processes of these nerve cells pass in the opposite direction and form the optic tracts. These partially decussate in the optic chiasma in such a

[illegible]

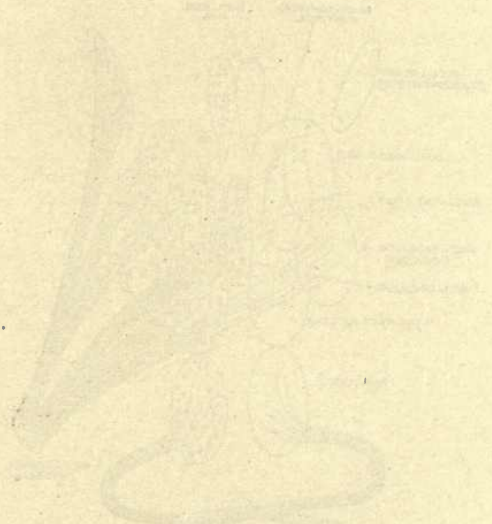


Fig. [illegible] —Diagram of the course of [illegible]

[illegible]

The Third, Fourth and Sixth Nerves.—The third, fourth and sixth nerves may be regarded as arising from the continuous [illegible] extending from the level of the [illegible] of the superior corpora quadrigemina [illegible]

The [illegible] portion of this [illegible] that belonging to the third nerve, may be divided into [illegible] portion, [illegible] lateral portion, [illegible] (Figs. [illegible])

[illegible]

manner that only the fibers from the internal half of each retina cross. The optic tracts end posteriorly in the pulvinar of the optic thalami, the external geniculate body and the superior corpora quadrigemina. From these connections nerve fibers enter the posterior portion of the internal capsule and pass by the optic radiations to the occipital lobes. This nerve transmits visual sensations.

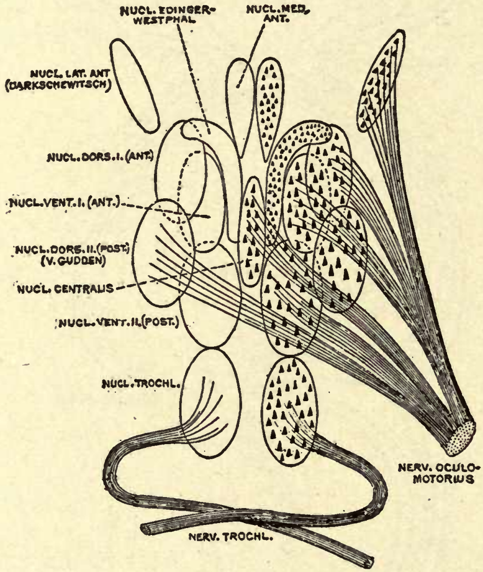


Fig. 140.—Diagram of the groups of cells forming the nuclei of the third and fourth nerves. (Quain.)

The fibres from the nucleus of Darkschewitsch to the oculo-motor nerve are doubtful.

The Third, Fourth and Sixth Nerves — The *third and fourth and sixth nerves* may be regarded as arising from one continuous elongated nucleus, extending from the level of the striæ acusticæ in the fourth ventricle to the superior corpora quadrigemina, close to the middle line.

The anterior portion of this nucleus, that belonging to the third nerve, may be divided into different portions, a more lateral large-cell portion, a superficial small-cell portion and another median portion of large cells. (Figs. 140 and 141.)

Stimulation from before backward beginning at the posterior

boundary of the third ventricle gives contraction of the ciliary muscle (changing the curvature of the lens of the eye), contraction of the pupil, of the internal rectus, the superior rectus, the levator palpebræ superioris, the inferior rectus and the inferior oblique. Finally, when the nucleus of the fourth nerve is reached, we obtain contraction of the superior oblique, and when the sixth nerve is reached, contraction of the external rectus.

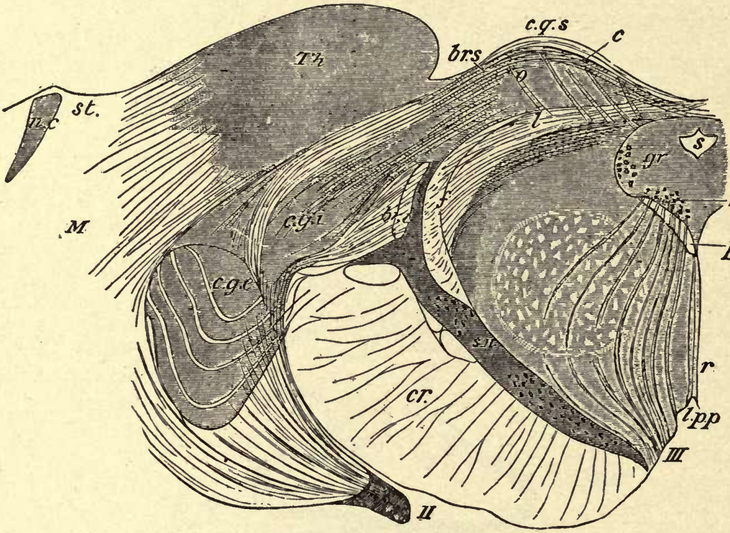


Fig. 141.—Section through the upper part of one of the anterior corpora quadrigemina and the adjacent part of the thalamus. (Quain.)

s., aqueduct; *gr.*, gray matter of aqueduct; *c. q. s.*, quadrigeminal eminence, consisting of: *l.*, stratum lemnisci; *o.*, stratum opticum; and *c.*, stratum cinereum; *Th.*, thalamus (pulvinar); *c. g. i.*, *c. g. e.*, internal and external (mesial and lateral) geniculate bodies; *br. s.*, *br. i.*, superior and inferior brachia; *f.*, fillet; *p. l.*, posterior (dorsal) longitudinal bundle; *r.*, raphe; *III*, third nerve; *nIII*, its nucleus; *l. p. p.*, posterior perforated space; *s. n.*, substantia nigra; above this is the tegmentum with its nucleus, the latter being indicated by the circular area; *cr.*, crusta; *II*, optic tract; *M.*, medullary centre of the hemisphere; *n. c.*, nucleus caudatus; *st.*, stria terminalis.

All these nuclei, as also the endings of the optic nerves in the superior corpora quadrigemina, are connected by means of the posterior longitudinal bundle, so that means are provided for accurate coördination, not only between the oculo-motor nuclei themselves, but because many of the fibers of the posterior longitudinal bundle are axons of cells of Deiters' nucleus, with also

the great [illegible] of coordination of the whole body [illegible].

The [illegible] tract between the superior [illegible] and the cerebellum [illegible] of the [illegible] with the [illegible] of the [illegible] with the [illegible] of the rest of the body.

The function of the [illegible] motor [illegible] is not [illegible]. [illegible] a large proportion of afferent fibers from the muscles of the eyeball. [illegible] of the eyeball [illegible] carried out [illegible].

The Fifth Nerve.—The fifth nerve is both motor and sensory. It supplies [illegible] from the [illegible] of the face and [illegible]. Its motor [illegible] supply the muscles of mastication. [illegible].

The Seventh Nerve.—The seventh cranial nerve is largely motor to the muscles of the face and [illegible] of the [illegible]. [illegible]

The Eighth Nerve.—The eighth cranial nerve [illegible] sensory [illegible]. [illegible]

[illegible]

the great centers of coördination of the whole body in the cerebellum.

The important tract between the superior corpora quadrigemina and the cerebellum indicate that the connections of the former with the optic nerves chiefly serve the function of coördination of visual impulses with the movements, not only of the eye, but also of the rest of the body.

The function of the oculo-motor nerves is not entirely motor. They contain a large proportion of afferent fibers from the muscle of the eye-ball. After total desensitization of the eye-ball by cocaine or by section of the fifth nerve, the movements of the eye-ball will be carried out with as much precision as under normal conditions.

The Fifth Nerve — *The fifth nerve is both motor and sensory.* It supplies sensation from the whole of the face and interior of the mouth. Its motor fibers supply the muscles of mastication. It also supplies the tensor tympani muscle. It contains trophic fibers.

The Seventh Nerve — The seventh cranial nerve is largely motor to the muscles of the face and some of the internal ear muscles. Through the nervus intermedius of Wrisberg, which is usually included as part of the seventh nerve but should really be considered a separate nerve containing efferent secretory fibers to the submaxillary and sublingual glands and afferent fibers, conveying impulses of taste and general sensibility from the tongue backwards from the geniculate ganglion.

The Eighth Nerve — *The eighth nerve possesses two definite functions. Its auditory branch* carries impulses from the sensory auditory epithelium. Its fibers originate in the bipolar cells of the ganglion of Scarpa.

The nerve enters the medulla immediately beneath the pons, and terminates in its dorsal and its ventral nucleus. From these nuclei the auditory impulses pass to the brain by way of the trapezium, the lateral fillet, the inferior corpora quadrigemina and the auditory radiations. The *vestibular branch* originates in the ganglion of the cochlea. The peripheral processes of these cells end in the sensory epithelium of the ampulla of the semicircular canals and of the saccule and utricle. (Fig. 142.) The nerve enters the medulla with the auditory division and passes to the dorsal nucleus

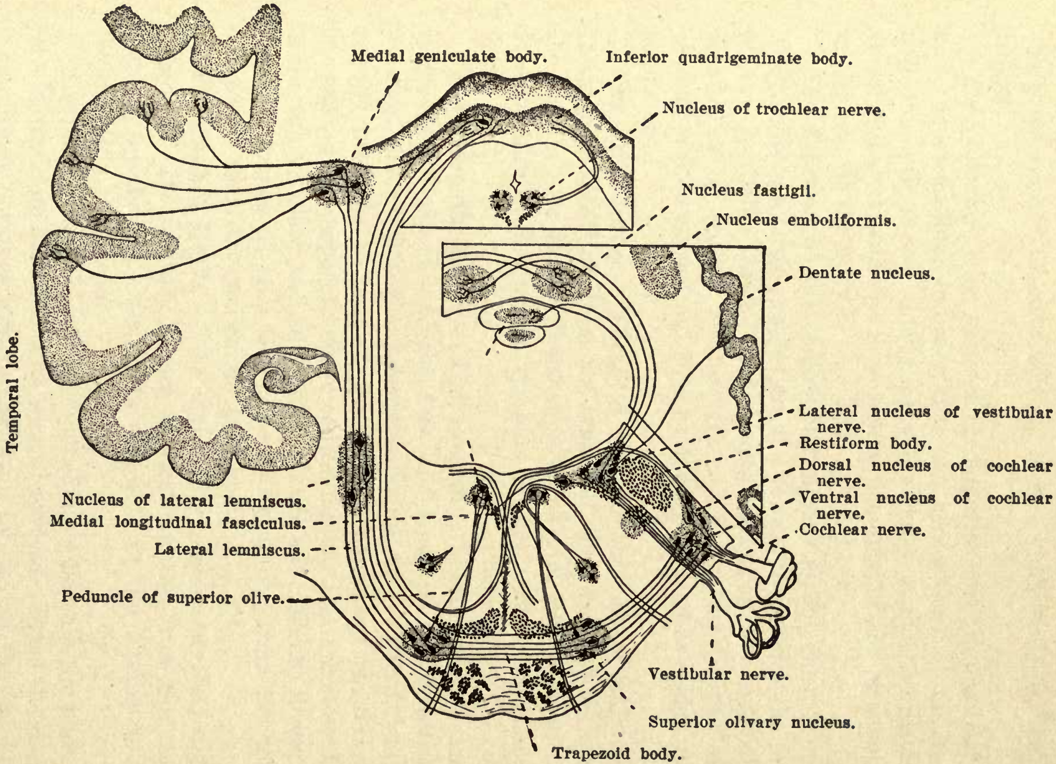


Fig. 142.—Scheme showing some of the central connections of the acoustic nerve. (Morris.)

[illegible] It makes connections with the [illegible] [illegible] Through the [illegible] [illegible]

Through [illegible] the [illegible] [illegible]

The Ninth Nerve.—The ninth and tenth cranial nerves are closely related. [illegible] Both these nerves contain efferent [illegible] arising from [illegible]

The following are the functions of the ninth cranial nerve: (1) [illegible] (2) [illegible] (3) [illegible] (4) [illegible]

The Tenth Nerve.—The tenth or pneumogastric nerve is the longest nerve in the body; its connections are more extensive and its functions more varied and important than perhaps any other single nerve.

Its efferent functions are: (1) [illegible] (2) [illegible] [illegible]

[illegible]

beneath the trigonum acusticum. It makes connections with the nucleus of Dieters and Bechterew. Some of its fibers pass directly to the cerebellum. The vestibular never transmits only sensations of equilibrium. Thus it is that its most important connections are with the cerebellum, that central mass of gray matter the chief function of which is to preside over equilibrium. Through the vestibulo-spinal tract the vestibular impulses affect the spinal centers.

Through the posterior longitudinal bundle the nuclei of the third, fourth and sixth nerves become coördinated with the vestibular impulses, and through the superior cerebellar peduncle by way of the red nucleus and optic thalamus these same impulses reach the cerebral cortex and excite there efferent motor impulses which may still further influence the motor mechanism of the spinal cord.

The Ninth Nerve — The ninth and tenth cranial nerves are chiefly sensory. The central nuclei form one continuous column lateral to the motor nuclei beneath the floor of the fourth ventricle. Both these nerves contain efferent fibers arising from nuclei internal and ventral to the sensory nuclei. The chief motor nucleus of the tenth nerve is the nucleus ambiguus.

The following are the functions of the ninth cranial nerve: (1) Motor to the muscles of the pharynx and base of the tongue. (2) Secretory fibers to the parotid gland by way of the optic ganglion. (3) Sensory fibers from the tongue, mouth and pharynx. (4) Inhibitory fibers to the respiratory center.

The Tenth Nerve — The tenth or pneumogastric nerve is the longest nerve in the body. Its connections are most numerous and its functions more varied and important than, perhaps, any other single nerve.

Its efferent functions are: (1) Motor to the levator palati and three constrictors of pharynx. (2) Motor to larynx. (3) Inhibitory to the heart. (4) Motor to muscles of esophagus, stomach, and small intestines. (5) Motor to unstriated muscle in the walls of the bronchi and bronchioles. (6) Secretory to glands of stomach and possibly pancreas.

Its afferent functions are: (1) Regulate inspiration, accelerate and promote inspiration or increase expiration as in coughing. (2)

[illegible] It is the inhibitor of the heart.

The Eleventh Nerve.—The eleventh (spinal accessory) nerve should not be considered as a cranial nerve. [illegible] which takes origin by series of roots [illegible] from cells in the [illegible] portion [illegible] It is a purely motor nerve to [illegible] muscles.

The Twelfth Nerve.—The twelfth (hypoglossal) nerve arises from cells under the [illegible] in the floor of the lower half of the fourth ventricle. It is the motor nerve to [illegible] muscles of the tongue and [illegible] bone and [illegible] muscles of the larynx.

THE FUNCTIONS OF THE VARIOUS PORTIONS OF THE BRAIN

Methods of Study.—Several methods are available for ascertaining the functions of the brain.

1. A knowledge of the anatomy of connections of the tracts within the brain furnishes us with information about the functions of the brain which [illegible]. It is for this reason that a detailed study of the anatomy of the brain has been necessary.

(2) Considerable information about the functions of various portions of the brain is obtained from a study of the differences in the histological structure of the brain.

(3) Direct experimentation by [illegible] of portions of the brain enable us to learn the function of the portion experimented upon.

(4) The study of [illegible] associated with lesions or disease of the brain [illegible]

The function of [illegible] brain [illegible] movements.

We have seen that the animal with only a spinal cord is a machine for [illegible] The [illegible] muscles belonging to the same level [illegible] These are [illegible]

Depressor and pressor from heart to vasomotor center. (3) Reflex inhibition of the heart.

The Eleventh Nerve — The *eleventh or spinal accessory nerve* should not be considered as a cranial nerve. Filaments enter it which take origin by series of roots coming from cells in the interior horn of cord as low down as the sixth cervical nerve (spinal portion), but continuous above with those of the accessory portion. It is a purely motor nerve to the trapezius and sternomastoid muscle.

The Twelfth Nerve — The twelfth cranial nerve arises from cells under the trigonum hypoglossi in the floor of the lower half of the fourth ventricle. It is purely motor in function, supplying the muscles of the tongue and those muscles attached to the hyoid bone and the extrinsic muscles of the larynx.

THE FUNCTIONS OF THE VARIOUS PORTIONS OF THE BRAIN

Methods of Study — Several methods are available for investigating the functions of the brain.

(1) A knowledge of the anatomical connections of the tracts within the brain furnishes in itself information upon the functions of the brain which is second to none in importance. It is for this reason that a detailed study of the anatomy of the brain has been necessary.

(2) Considerable information upon the function of various portions of the brain is available from a study of the differences in the histological structure of the brain.

(3) Direct experimentation by isolation or ablation of portions of the brain enable us to know the function of the portion operated upon.

(4) The study of the symptoms of human beings affected with tumors or other diseases of the brain producing its destruction.

The function of any portion of the brain must depend solely upon the efferent tracts which leave it and the afferent tracts entering it.

We have seen that the animal with only a spinal cord is a machine for the performance of certain reflexes. The reflexes involve particularly muscles belonging to the same level as the stimulated afferent nerves. They are inevitable and contain no

incalculable element. The frog is best adapted for an experimental investigation of such a character.

If we investigate in this manner the brain we begin by dividing the bulb by a section between the medulla and pons. Such an animal is called the bulbo-spinal animal. It will present certain phenomena not present in the spinal animal and determined by the character of the afferent nerves having their nuclei in the bulb.

The Afferent Impulses Received by the Medulla — The bulb receives: (1) Afferent impressions of taste from the tongue through the nervus intermedius. (2) Through the ninth, afferent impressions from the tongue and pharynx. (3) Through the vagus afferent impulses from the whole alimentary canal to the ileocolic sphincter and from the lungs and heart.

Efferent Impulses Passing from the Medulla — It also sends efferent fibers from the nucleus ambiguus to the larynx, bronchi, esophagus, stomach and intestines, secretory fibers to the stomach and inhibitory fibers to the heart.

The eighth nerve is divided, even if all of its nucleus is not by the section. The twelfth nerve supplying the muscles of the tongue is preserved.

The Bulbo-Spinal Animal and How It Differs from the Spinal Animal — The preservation of these additional centers makes it possible for the bulbo-spinal animal to maintain those visceral functions which are under the nervous control of the bulb. The blood pressure will not show the great fall present in the spinal animal. The animal will also continue to breathe regularly and its heart rate will remain normal. All these functions may be affected by appropriate stimuli.

There is, moreover, a certain, though ill defined, dependence of the skeletal muscles upon the visceral functions; so that, with the preservation of the visceral nervous control, there is a greater stability in the response of the bulbo-spinal animal to reflexes.

It is easier to evoke movements in all four limbs. The key to the situation is the preservation of visceral functions and the nexus between these and the skeletal motor functions. The mechanism by which food, including oxygen, is seized, tasted, swallowed and digested and its distributions in part controlled is preserved. If in the frog the eighth nerve has been left intact a certain amount

as the sense of equilibrium is preserved. The animal will try to right itself, if laid on its back, and can swim.

The Pontine Bulbo-Spinal Animal.—In order to investigate this, the brain must be divided by a section at the upper border of the pons. The nuclei of the fifth and sixth nerves have now been removed, as have the lower [illegible] of the organ of hearing and the important [illegible] the nucleus of the vestibular branch of the eighth nerve. Such an animal is able to walk, stand and swim. When placed on its back it immediately turns over and will compensate the rotation of a turn table, when placed upon it, by turning its eyes in the opposite direction.

The controlling influence of the midbrain upon the independent reflex excitability of the lower centers is made evident by its removal from the pontine-spinal animal. If after section above the pons the cerebellum is also removed, the animal becomes spontaneously active, crawling about until blocked by some obstacle. There is also an increased activity of the swallowing reflex, anything touching the mouth is snapped at.

In the mammal there is a similar increase of reflex activity, but the power of progression is not retained.

The Animal Possessing the Brain and Cord All Below the Upper Level of the Mid-Brain.—*The Functions of the Mid-Brain.* —When the midbrain is preserved by a section in front of the anterior corpora quadrigemina, the animal will be in possession of all its general movements and the different parts [illegible] all the [illegible] except the [illegible]. In the mammal such a condition causes "decerebrate rigidity." The limbs are held stiffly be held rigidly in a position of extension and to be passive [illegible]. The condition would appear to be due in part to the increased activity of the lower centers, especially of the [illegible], since it is at once abolished by section of the posterior spinal roots, and in part to the removal of the inhibitory impulses normally descending the [illegible] spinal tracts. It must be remembered that the pyramidal tracts in the frog are represented by only a few fibers.

The Animal Possessing the Optic Thalami All the Brain and Cord Below Them.—The removal of the cerebral hemispheres alone, that is, [illegible] leaves the frog with all that is necessary for [illegible]; the

of the sense of equilibrium is preserved. The animal will try to right itself if laid on its back, and usually succeeds.

The Pontine Bulbo-Spinal Animal — In order to investigate these the brain must be divided by a section at the upper border of the pons. The motor nuclei of the fifth and sixth nerves have now been preserved, as have the lower nuclei of the organ of hearing and the important organ of static sense, the nucleus of the vestibular branch of the eighth nerve. Such an animal is able to walk, spring and swim. When placed on its back it immediately turns over and will appreciate the rotation of a turn-table, when placed upon it, by turning its eyes in the opposite direction.

The controlling influence of the cerebellum upon the independently excessive excitability of the lower centers is made evident by its removal from the pontine-spinal animal. If after section above the pons the cerebellum is also removed, the animal becomes spontaneously active, crawling about until blocked by some obstacle. There is also an increased activity of the swallowing reflex, anything touching the mouth is snapped at.

In the mammal there is a similar increase of reflex activity, but the power of progression is not retained.

The Animal Possessing the Brain and Cord, All Below the Upper Level of the Mid-Brain — *The Functions of the Mid-Brain* — When the mid-brain is preserved by a section in front of the anterior corpora quadrigemina, the animal will be in possession of all its sensory impressions and the efferent paths to all the eye muscles except the olfactory sense. In the mammal such a condition causes "decerebrate rigidity." The limbs are held more or less rigidly in a position of extension and resist passive flexion. The condition would appear to be due in part to the increased activity of the lower centers, especially of the cerebellum, and is reflex, as it is at once abolished by section of the posterior spinal roots, and in part to the removal of the inhibitory impulses normally flowing through the cerebro-spinal tracts. It must be remembered the pyramidal tracts in the frog are represented by only a few fibers.

The Animal Possessing the Optic Thalami, All the Brain and Cord Below Them — The preservation of the optic thalami, that is, the removal of the cerebral hemispheres alone, leaves the frog with all that is necessary for the response to any stimulus. Un-

less the animal is observed carefully one would fail to notice anything wrong with the animal. It sits up in its customary attitude, jumps away, guides itself perfectly by sight. It will swim about in water until it finds a support upon which it will crawl out. It will crawl up an inclined board and if the inclination is gradually increased until the board is rotated on its lower end the frog will crawl up one side and down the other.

One of the differences between such an animal and the normal animal is the complete absence in the former of spontaneous motion. It is an extremely complex and, in contrast to the previously described animal, an extremely accurate and well-balanced machine. Every movement, however, must be provoked by a closely related external stimulus.

If care has been taken to preserve the optic thalami in such an animal it will occasionally show spontaneous movements, such, for instance, as attempts to [illegible] as if to [illegible] upon the approach of a fly. If the optic thalami have been preserved in fishes they show very little difference from the normal fish.

On the other hand, elasmobranch fishes which depend mainly upon the olfactory apparatus, the removal of merely the olfactory lobes and cerebral hemispheres produces almost complete paralysis even though the optic lobes and thalami are intact.

The animal contains no [illegible] element. It feels no hunger or thirst. The bird acts much as the frog. It is able to walk about avoiding obstacles and even to fly. It is unable to recognize food or enemies of its own species. It shows no fear.

The whole of the cerebral hemispheres have been successfully removed in a dog. It was able to walk normally and spent most of the day in walking up and down its cage. It slept soundly at night. In pinching its skin it would turn around and snarl and attempt to bite. It could not recognize food, showed no fear or pleasure on recognition of those who fed it. All memory was gone.

Functions of the Cerebellum.—We have seen that there are two distinct classes of afferent stimuli; we may speak of them as two systems of afferent nerves.

1. Exteroceptive or stimuli coming from the surface of the body or striking it from a distance.

2. Proprioceptive or afferent stimuli from the interior of the

less the animal is observed critically one would fail to notice anything wrong with the animal. It sits up in its position, on interference jumps away, guides itself perfectly by sight. It will swim about in water until it finds a support upon which it will crawl out. It will crawl up an inclined board and if the inclination is gradually increased until the board is rotated on its lower end, the frog will crawl up one side and down the other.

The single difference between such an animal and the normal animal is the entire absence in the former of spontaneous motion. It is an extremely complex and, in contrast to the previously described animal, an extremely accurate and well-balanced machine. Every movement, however, must be provoked by a closely related external stimulus.

If care has been taken to preserve the optic thalami in such an animal it will occasionally show spontaneous movements, such, for instance, as attempts to bury itself as if to hibernate upon the approach of winter. If the optic thalami have been preserved in fishes they show very little difference from the normal fish.

On the other hand, elasmobranch fishes which depend mainly upon the olfactory apparatus, the removal of merely the olfactory lobes and cerebral hemispheres produce almost complete paralysis, even though the optic lobes and thalami are intact.

The animal contains no incalculable element. It feels no hunger or fear. The bird acts much as the frog. It is able to walk about avoiding obstacles and even to fly. It is unable to recognize food or enemies or its opposite sex. It shows no fear.

The whole of the cerebral hemispheres have been successfully removed in a dog. It was able to walk normally and spent most of the day in walking up and down its cage. It slept soundly at night. In pinching its skin it would turn around and snarl and attempt to bite. It could not recognize food, showed no fear or pleasure or recognition of those who fed it. All memory was gone.

Functions of the Cerebellum — We have seen that there are two distinct classes of afferent stimuli; we may speak of them as two systems of afferent nerves.

1. *Exteroceptive* or stimuli coming from the surface of the body or striking it from a distance.

2. *Proprioceptive* or afferent stimuli from the interior of the

body, the muscles, joints and tendons. This second system has its head ganglion in the cerebellum. By its afferent nerves it receives information as to the exact position of the limbs and the degree of contraction of the muscles. As a part of this system must be included the afferent elements entering the vestibular branch of the eighth nerve, conveying those impressions of static sense which have reference to the body as a whole.

The head ganglion of this system is the cerebellum. All its impressions are received and properly balanced against one another in this organ and that the correct efferent impulses discharged to the higher parts of the central nervous system, but also downwards to the spinal cord through the vestibulo-spinal tract and the cerebro-spinal tracts, to produce that proper degree of relative contraction and relaxation of opposing sets of muscles which will result in a perfection of coördination not only in the normal posture preserved during rest but also in the movements, which are superimposed by the higher parts of the central nervous system or by the pathways of the spinal cord.

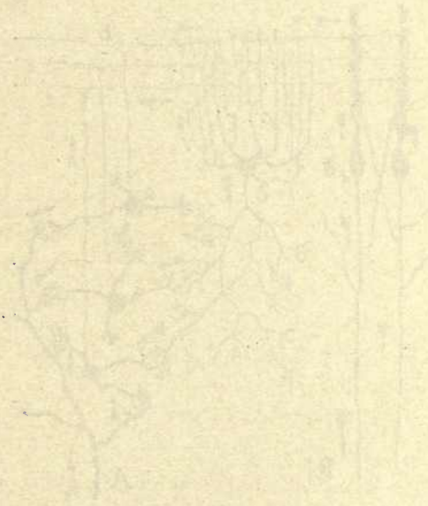


Fig. 143.—Section of the cerebellar cortex showing the probable path of nerve impulses. (Cajal.)

A, ascending fiber ending in contact with dendrites of a Purkinje cell; B, [illegible] fiber; a, [illegible] cell; [illegible] a basket cell; [illegible].

The Histology of the Cerebellar Cortex.—The cortex of the cerebellum consists of the following two layers between which are situated cells called the cells of Purkinje. (Figs. 143 and 144.)

1. Molecular Layer.—Its characteristic cell is provided with a dendrite which runs parallel with the surface. From this axon collateral fibers run downward, to end in a basket-like arborization around the cells of Purkinje.

body, the muscles, joints and tendons. This second system has its head ganglion in the cerebellum. By its afferent nerves it furnishes information as to the exact position of the limbs and the degree of contraction of the muscles. As a part of this system must be included the afferent stimuli entering the vestibular branch of the eighth nerve, conveying those impressions of static sense which have reference to the body as a whole.

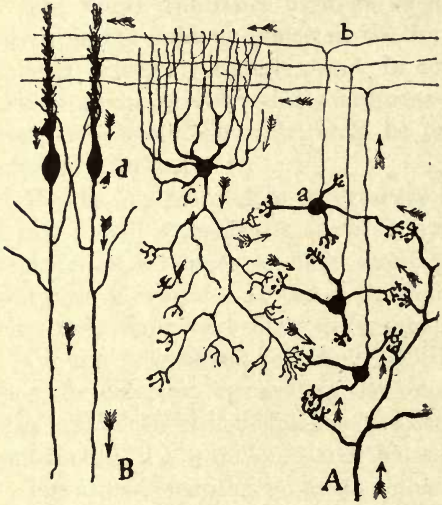


Fig. 143.—Cells of the cerebellar cortex, showing the probable path of nerve-impulses. (Quain.)

A, a moss-fibre (afferent); *B,* an axon of a Purkinje cell (efferent); *a,* granules; *b,* their axons; *c,* a Golgi cell; *d,* two Purkinje cells.

The head ganglion of this system is the cerebellum. All its impressions are received and properly balanced against one another in this organ and just the correct efferent impulses discharged to the higher parts of the central nervous system, but also indirectly to the spinal cord through the vestibulo-spinal tract and the cerebro-spinal tracts, to produce just that proper degree of relative contraction and relaxation of opposing sets of muscles which will result in a perfection of coördination, not only in the normal tone preserved during rest but also in the variations of contractions incidental to the muscular activities, which are superimposed by the higher parts of the central nervous system or by the pure reflexes of the spinal cord.

The Histology of the Cerebellar Cortex — The cortex of the cerebellum consists of the following two layers between which are situated cells, called the *cells of Purkinje:* (Figs. 143 and 144.)

1. Molecular layer — Most external, its characteristic cell is star-shaped with an axon which runs parallel with the surface. From this axon collateral fibers dip internally, to end in a regular basket-like arborization around the cells of Purkinje.

3. Granular or nuclear layer. — It contains two kinds of cells:

(a) Small cells with dendrites and one axon which runs straight out into the molecular layer where it bifurcates into two branches running up parallel to the surface and resting upon the tips of the tree-like arborization of Purkinje's cells.

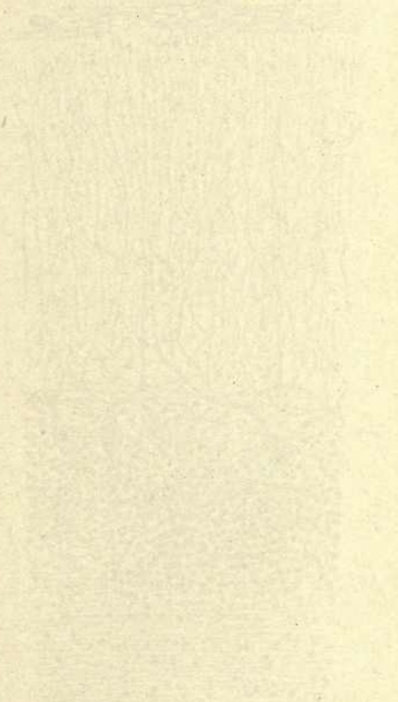


FIG. [illegible]. — Section of cortex of cerebellum [illegible]

(b) Golgi's cells. — Cells with many dendrites terminating in the neighboring gray matter.

There are two kinds of afferent fibers to the cerebellar cortex and one set of efferent fibers:

1. Mossy fibers. — Afferent fibers presenting mossy thickenings and terminating by [illegible] branches in the gray matter.

2. Tendril fibers, also afferent, ending by arborization around the base of the cells of Purkinje.

3. Axons of the cells of Purkinje run down into the white matter to end around the cells of the dentate nucleus. No efferent fiber from the cortex of the cerebellum leaves the cerebellum.

The cells of Purkinje are large flask-shaped cells with one dendrite and one axon from the base of the cell. The one dendrite is characterized by the richness of its branchings.

The Afferent Tracts to the Cerebellum by Way of the Three Peduncles. — The afferent tracts of the cerebellum are:

1. Through restiform body. — (1) Axons of Clarke's column of cells by direct cerebellar tract.

(2) From the nuclei gracilis and cuneatus of the same and opposite sides.

2. Granular or nuclear layer — It contains two kinds of cells: (*a*) Small cells with dendrites and one axon which runs straight up into the molecular layer where it bifurcates into two branches running parallel to the surface and resting upon the tips of the tree like arborization of Purkinje's cells.

Fig. 144.—Section of cortex of cerebellum. (Quain.)

a, pia mater; *b*, external layer; *c*, layer of corpuscles of Purkinje; *d*, inner or granule layer; *e*, medullary centre.

(*b*) *Golgi's cells* — Cells with many dendrites terminating in the neighboring gray matter.

There are two sets of afferent fibers to the cerebellar cortex and one set of efferent fibers.

1. *Moss fibers* — Afferent fibers presenting curious thickenings and terminating by frequent branches in the gray matter.

2. *Tendril fibers,* also afferent ending by arborization around the base of the cells of Purkinje.

3. *Axons of the cells of Purkinje* run down into the white matter to end around the cells of the deep nuclei. No efferent fiber from the cortex of the cerebellum leaves the cerebellum.

The cells of Purkinje are large, flask-shaped cells with one apical dendrite and one axon from the base of the cell. The one dendrite is characterized by the richness of its branching.

The Afferent Tracts to the Cerebellum by Way of the Three Peduncles — The afferent tracts of the cerebellum are:

Inferior Peduncle — (1) Axons of Clark's column of cells by posterior cerebellar tract.

(2) From the nuclei gracilis and cuneatus of the same and opposite side.

(3) From vestibular nerve directly and indirectly from Deiters' nucleus.

(4) Inferior olive of chiefly the opposite side.

Middle Peduncle.—Chiefly afferent and partly efferent to and from the formatio reticularis. By means of the nuclei of the formatio reticularis connections are established between the frontal and temporal lobes of the brain.

Superior Peduncle.—(1) From the superior corpora quadrigemina [illegible] the cortical gray matter, and thus connections are established between the optic nerve and oculomotor and the cerebellum.

(2) The [illegible] being sent from the [illegible] cord.

The Spinal Tracts from the Cerebellum.—From the roof [illegible] the impulses upon the coordination of the [illegible] of [illegible] are passed on to the [illegible] of the [illegible] and by the superior cerebellar peduncle to the red nucleus and subthalamic region. Fibers also pass from the red nucleus to the anterior corpora quadrigemina.

As [illegible] pass directly from the cerebellum to the cord, but from [illegible] which are closely connected with the roof nuclei of the cerebellum, there are [illegible] to the cord in the vestibulo-spinal tract.

Muscular movements may be evoked by stimulation of the cerebellum. Electrical stimuli [illegible] applied to the cortex of the cerebellum no movements are evoked. It is not likely, therefore, that any of the cerebellar efferent fibers leave the cortex. On the other hand, when stimuli are applied to the central nuclei movements are evoked. Stimulation of the roof nuclei will produce movements of the eyes and head.

Stimulation of the nuclei of the lateral lobes, the nucleus dentatus, will produce movements of the trunk and limbs. The movements evoked are coordinated, as [illegible] in walking and [illegible] of the limbs.

Behavior of the Cerebellum in Animals.—The functions of the cerebellum are best shown after the removal of the whole or [illegible] part. Complete or partial extirpation of the cerebellum leaves the animal [illegible] with [illegible] disturbances:

(1) Ataxia or loss of power on the same side of the body.

(2) Atonia, [illegible] or loss of [illegible] on the same side.

(3) From vestibular nerve directly and indirectly from Deiters' nucleus.

(4) Inferior olive of chiefly the opposite side.

Middle Peduncle — Partly afferent and partly efferent to and from the formatio reticularis. By means of the nuclei of the formatio reticularis connections are established between the frontal and temporal lobes of the brain.

Superior Peduncle — (1) From the superior corpora quadrigemina to the cortical gray matter, and thus connections are established between the optic nerve and oculo-motor and the cerebellum.

(2) The anterior cerebellar tract from the spinal cord.

The Efferent Tracts from the Cerebellum — From the roof ganglia the impulses from the termination of the axons of the cells of Purkinje are passed on to the pons by the middle peduncle and by the superior cerebellar peduncle to the red nucleus and subthalamic region. Fibers also pass from the roof nuclei to the superior corpora quadrigemina.

No tract runs directly from the cerebellum to the cord, but from Deiters' nucleus, which is closely connected with the roof nuclei of the cerebellum, fibers run downward to the cord in the vestibulo-spinal tract.

Muscular movements may be excited by stimulation of the cerebellum. Unless very strong stimuli are applied to the cortex of the cerebellum no movements are excited. It is not likely, therefore, that any of the cerebellar efferent fibers leave the cortex. On the other hand, when weak stimuli are applied to the central nuclei movements are excited. Stimulations of the roof nuclei will produce movements of the eyes and head.

Stimulation of the nuclei of the lateral lobes, the nucleus dentatum, will produce movements of the trunk and limbs. The movements evoked are concerned in maintaining equilibrium and involve every muscle of the body.

Behavior of the Cerebellarless Animal — The functions of the cerebellum are made more clear by removing it in whole or in part. Complete unilateral extirpation of the cerebellum leaves the animal (e. g., the dog) with three cardinal symptoms:

(1) Asthenia or loss of power on the same side of the body.

(2) Atonia — considerable loss of tone on the same side.

(c) Ataxia.—Tremors, or ill-limited movements, accompany any voluntary movement. A dog deprived of the cerebellum upon one side at first is unable to stand but later recovers the power to walk, though the hind leg drops and tremors accompany every movement. The animal tends to fall toward the side of the lesion. If attempting it supports itself against any wall or support. When the whole cerebellum has been removed the animal is unable to walk for months. After a time it learns to do so but shows an ataxia which is quite different from spinal ataxia and may best be described as a top-heavy ataxia. It is an ataxia presenting similar to the staggering of a drunken man. The compensation which is accomplished is probably by means of the cerebrum. Removal of the hemispheres now produces permanent inability to walk. The animal now being without a functioning cerebellum is without those impulses which normally constantly stream out from it in response to the afferent impulses of the proprioceptive system and which directly or indirectly reach the cord.

In attempting to furnish an explanation of these symptoms of the cerebellar lesions we find a number of possibilities are present, all of which are possible factors. We have in the first place not merely an interruption of a large portion of the impulses concerning muscular sensations and of proprioceptive impulses of equilibrium through the vestibular nerve to the cerebellum, but also a loss of what is of greater importance, the operations of the mechanism which gathers up all the afferent impulses expressing the state of contraction of the individual muscles and the relation of the center of gravity of the whole body to its position, and which sends out as its response to these incoming afferent impulses a constant call upon the apparatus of the more peripheral portion of the nervous system for just the right degree of contraction and relaxation, of augmentation and inhibition, which affords the tone of rest and the steadying of the changing phases of muscular activities.

In response to the same incoming impulses there proceed from the higher portions of the nervous system a guided stream of impulses from the operations of a directing center for the correct adjustment of voluntary movements to the preservation of the desired position of the center of gravity. The failure of this apparatus leaves the animal without its most important guide in the adjustment of its movements. In its absence the animal must fall back upon the

(3) Astasia,— tremors, or rhythmical movements, accompanying any voluntary movement. A dog deprived of the cerebellum upon one side at first is unable to stand but later acquires the power to walk, though the hind leg drops and tremors accompany every movement. The animal tends to fall toward the side of the lesion. It attempts to support itself against any wall or support. When the whole cerebellum has been removed the animal is unable to walk for months. After a time it learns to do so but shows an ataxia which is quite different from spinal ataxia and may best be described as a top-heavy ataxia. It is an ataxia precisely similar to the staggering of a drunken man. The compensation, which is acquired after cerebellar lesions, is of cerebral origin. Subsequent removal of the hemispheres produces permanent inability to walk. The animal or human being without a functionating cerebellum is without those impulses which normally constantly stream out from it in response to the afferent impulses of the proprioceptive system and either directly or indirectly reach the cord.

In attempting to furnish an explanation of the symptoms of the cerebellarless animal a number of possibilities are present, all of which are possible factors. We have in the first place not merely an interruption of a large portion of the impulses conveying muscular sensations and of proprioceptive impulses of equilibrium through the vestibular nerve to the cerebellum, but also a loss of what is of greater importance: the operations of the mechanism which gathers up all the afferent impulses expressing the state of contraction of the individual muscles and the relation of the center of gravity of the whole body to its position, and which sends out as its response to these incoming muscular impulses a constant call upon the apparatus of the more peripheral portion of the nervous system for just the right degree of contraction and relaxation, or of augmentation and inhibition, which affords the tone of rest and the steadying of the changing phases of muscular activities.

In response to the same incoming impulses there passes to the higher portions of the nervous system a unified call as though from the operations of a clearing-house, for the correct adjustment of voluntary movement to the preservation of the desired position of the center of gravity. The failure in this apparatus leaves the animal without its most important guide in the adjustment of its movements. In its absence the animal must fall back upon the

mechanism which is inadequately furnished with proprioceptive muscular sensations and which lacks that interactive degree of coordination of all muscle concerned in any given movement which exists in the cerebellum.

Attempts have been made to show by many observers that the normal activity of the cerebellum is exerted either on the side of augmentation of muscular function (Luciani) and by others on the side of restraint of muscular function (Weir Mitchell, Russell, 1897). The latter view explains better the condition of hypertonicity following section of the cerebellar peduncle, the symptom of cerebellar ataxia, and the spontaneous activity of the frog after removal of the cerebellum and portion of the brain in front of the pons.

However this may be, the greatest emphasis should be laid on the fact that the important function of the cerebellum is the exercise of a control over muscular contraction, which control has, so to speak, for its aim the production of a perfect coordination in both states of rest and states of changing muscular activity.

In states of rest coordination is provided for through the more direct spinal relations of the cerebellum and during voluntary muscular activity the impulses may descend from the brain without an influence upon its direction being imparted to it, both in its incipiency as a result of the cerebral efferent impulses from the cerebellum and in its course as a result of the lower indirect efferent cerebellar connections with the lower spinal centers.

The cerebellar syndrome shows three principal symptoms, which are all referable to the same side in unilateral affection:

1. *Asthenia*—a slight loss of power or weakness.

2. *Atonia*—or loss of tone, a lowering in the firmness of the muscles, in other words.

3. *Astasia*—tremors or rhythmical movements of the muscles accompanying every willed movement.

All these three symptoms can be traced to the failure of normal degree of responsiveness of the muscles. Each contraction starts in a more relaxed muscle and therefore at less advantage, and so must require an extra voluntary effort to accomplish the same end. For this reason there is apparent weakness of the muscles; during rest an undue laxness and during movement a frequent under or over contraction, which results in tremors and irregular

cerebrum which is incompletely furnished with proprioceptive muscular sensations and which lacks that superlative degree of association of all tracts concerned in muscular movements which exists in the cerebellum.

Attempts have been made to show by some observers that the normal activity of the cerebellum is exerted rather on the side of augmentation of muscular function (Starling) and by others on the side of restraint of muscular function (Meyers, J. A. M. A., LXV, 16, 1348). The latter idea explains better the condition of decerebrate rigidity following section of the mid-brain anterior to the superior corpora quadrigemina, the symptom of adiadokocinesis, and the spontaneous activity of the frog after removal of the cerebellum and section of the brain in front of the pons.

However this may be, the greatest emphasis should be laid on the fact that the supreme function of the cerebellum is the exercise of a control over muscular contraction, which control has, so to speak, for its aim the production of a perfect coördination in both states of rest and states of changing muscular activity.

In states of rest coödination is provided for through the more direct spinal relations of the cerebellum and during voluntary muscular activity, no impulse may descend from the brain without an influence upon its direction being imparted to it, both in its incipiency as a result of the cerebrally afferent impulses from the cerebellum and in its course as a result of the lower indirect efferent cerebellar connections with the lower spinal centers.

The cerebellarless animal shows three principal symptoms which are all referable to the same side in unilateral ablations:

1. *Asthenia* — a slight loss of power or weakness.

2. *Atonia* — or loss of tone; a constant undue laxness of the muscles, in other words.

3. *Astasia* — tremors or rhythmical movements of the muscles accompanying every willed movement.

All these three symptoms can be traced to the failure of normal degree of responsiveness of the muscles. Each contraction starts in a more relaxed muscle and therefore at less advantage, and so must require an extra voluntary effort to accomplish the same end. For this reason there is apparent weakness of the muscles:— during rest an undue laxness and during movement a frequent under or over contraction, which results in tremors and inaccura-

ward of the movement is maintained. [illegible] necessary [illegible] be regular not only in the appropriateness as to speed of the impulses but to the kind of the organ of muscular coordination.

The cerebellar-less animal will at first be unable to stand or walk, but after several months may again be able to walk. The improvement is effected by [illegible] the cerebrum [illegible] remaining functions [illegible]. The gait, however, is then a wide straddling [illegible] characteristic. There is a constant tendency [illegible] for the centre of gravity to fall to one or the other side. It is a top-heavy body. The animal is less ready to take advantage of a wall against which it may lean during its movements. In order to correct this tendency for the centre of gravity to fall to one side or the other it widens its base of support as widely as possible. Such [illegible] cerebellar states with [illegible] and [illegible] are [illegible] under normal conditions.

There is then a tendency for the body to move too little, in order to place the centre of gravity in a correct position for balance. This tendency must be corrected by an extra and special compensative effort on the part of the cerebrum, so that the [illegible] movements are made with [illegible] to adopt a wide base of support and to stagger.

This form of ataxia is called cerebellar ataxia.

It must be distinguished from two other forms of ataxia. (1) Spinal or tabetic ataxia, accompanying lesions in the posterior columns of the cord and (2) ataxia due to lesion in the [illegible] tracts.

In tabes dorsalis the [illegible] and the [illegible], under the [illegible], is not furnished with information as to the degree of contraction within the muscles. If [illegible] from the results of its efforts by the use of the eyes [illegible]. The loss of this information produces the impairment in [illegible], on the [illegible] that a greater degree of movement is [illegible] than the necessary amount for the desired [illegible].

In addition, therefore, to the movements being inaccurate they are excessive. The vestibular and cerebellar mechanisms, however, are intact and [illegible] it is not that loss of the adjustments of the movements of the body as a whole to the correct position of the centre of gravity experienced in cerebellar ataxia. A lesion in the pos

cies of the movement to the desired end. This inaccuracy has its origin not only in the unpreparedness, so to speak, of the muscles, but in the loss of the organ of accurate coördination.

The cerebellarless animal will at first be unable to stand or walk, but after several months may again be able to walk. The compensation is cerebral, as when the cerebrum is then cut off, permanent paralysis follows. The gait, however, of such a cerebellarless animal is characteristic. There is a constant tendency, precisely as in a drunken man, for the center of gravity to fall to one or the other side. It is a top-heavy ataxia. The animal is ever ready to take advantage of a wall against which it may lean during its progression. In order to correct this tendency for the center of gravity to fall to one side or the other, it makes its base of support as wide as possible. Each diagonal movements starts with less advantages and is accomplished with less accuracy than under normal condition.

There is then a tendency for the feet to move too little, in order to place the center of gravity in a correct position for balancing. This tendency must be corrected by an extra and usually an inaccurate effort on the part of the cerebrum, so that excessive movements are made which cause the animal to adopt a wide base of support and to stagger.

This form of ataxia is called cerebellar ataxia.

It must be distinguished from two other forms of ataxia: (1) spinal or tabetic ataxia, accompanying lesions in the posterior columns of the cord, and (2) ataxia due to lesions in the pyramidal tracts.

In spinal ataxia the movements are excessive and inaccurate because the cerebrum is not furnished with information as to the degree of contraction within the muscles. It consequently can only know the results of its efforts by the use of the eyes. The loss of this information produces the impression, so to speak, on the cerebrum that a greater degree of movement is required than the customary amount for the desired end.

In addition, therefore, to the movements being inaccurate they are excessive. The cerebellar and vestibular mechanism, however, is intact and so there is not that loss of the adjustment of movements of the body as a whole to the correct position of the center of gravity experienced in cerebellar ataxia. A lesion in the pos-

terior columns illustrates defects dependent on a loss of one kind of function presided over in part by the cerebellum.

On the other hand, in lateral sclerosis, in which condition the lesion is in the pyramidal tracts, the cerebrum has lost the main path for both the activation and control of the motor mechanism of the spinal cord, and, in consequence, every reflex is exaggerated.

FUNCTIONS OF THE CEREBRUM

The Contrast between the Animal Possessing a Cerebrum and One Without a Cerebrum — When we investigate the functions of the cerebrum we at once are struck with a very important difference between the animal possessing a cerebral hemisphere and one without one. An animal deprived of its cerebral hemispheres can be played upon at will; a definite response will always follow a definite stimulus. With an animal possessing a cerebral hemisphere it is impossible to foretell just what response will follow any stimulus. In other words the response following a peripheral stimulus always is incalculable. Such an animal is influenced by many feelings involved in the action of its consciousness. Fear, anger, hunger, affection, will all cause a modification of stimulated reflexes. The question suggests itself, and did long ago when this subject was first considered, are certain areas in the cerebral cortex devoted to the exclusive origination of these various impulses or feelings which control our actions? On both theoretical and experimental grounds the cerebral cortex cannot be thus divided into areas which represent the various predominating states which characterize our consciousness.

The Foundation of all Mental Activity upon Association of Ideas (Association of Intracerebral Groups of Impulses) — Ablation of various portions of the brain does not remove any one form of activity characterizing our intelligence, but rather induces a reduction of intelligence as a whole. The whole science of phrenology has no basis in fact. On the other hand certain portions of the brain are intimately associated with definite forms of cerebral activity, but only with those forms of cerebral activity which, if we may be excused for using the term, stand immediately next to the outside world on both the afferent and efferent end of the chain of links which constitutes perception, judgment, volition and finally action.

The afferent and efferent end of this chain may be [illegible] and action.

The intermediate forms of cerebral activity, upon which judgment and volition are based, those which determine what action shall follow what is perceived, are also related to many parts of the cerebral cortex and are only possible because of the faculty called memory. But what is memory? Only registration of former experiences within the mind. [illegible] old experiences will [illegible] cerebral paths used in former experiences [illegible] formerly associated with these [illegible].

The association fibers connecting the different areas and the old [illegible] in the mind without [illegible] the brain of all the association fibers in the brain which were built in them. [illegible] portions of the brain [illegible] perception and action, though these portions may be very distant from one another. And so it is that all the brain is used in most of our complex acts and thinking of every kind.

The Localization of Function in the Perceptive and Motor End of the Chain of Cerebral Activities. — All in the above paragraph [illegible] portions of the brain are definitely related to certain forms of cerebral activity. It is, however, only the perceptive and motor ends of this chain of cerebral events which can be [illegible] within the cerebral cortex. [illegible] the motor [illegible] system, which [illegible] the [illegible] of the motor [illegible]. The motor areas of the human brain are all within the ascending frontal convolution. [illegible] the portions which control the movements of the leg, arm and head (Fig. 147 [illegible]).

[illegible] of this [illegible] movements of the leg, arm and head. In the lower monkeys these areas are [illegible] as they are in the higher apes or in human beings. Indeed in the [illegible] these areas are [illegible] may be stimulated by weak electrical current [illegible] cortex [illegible] of the gray matter.

The afferent and efferent end of this chain may be characterized as perception and action.

The intervening forms of cerebral activity, upon which judgment and volition are based, those which determine what action shall follow what is perceived, call into activity many parts of the cerebral cortex and are only possible because of the faculty called memory. But what is memory? Only repetition of former experiences within the mind, the actual use of all the old previously well worn cerebral paths used in former experiences minus the actual external afferent impulses normally associated with these experiences.

The *association tracts* constitute the old paths and the old experiences cannot again be actuated in the mind without the use by the brain of all the association tracts in the brain which were utilized in those former experiences, and by again bringing into relation with each other portions of the brain directly connected with perception and action, though these portions may be very distant from one another. And so it is that all the brain is used in most of our intellectual acts and states of consciousness.

The Localization of Function in the Perceptive and Action End of the Chain of Cerebral Activities — All in the above paragraph is very far from meaning that no portions of the brain are definitely related to certain forms of cerebral activity. It is, however, only the perception and action end of the chain of cerebral events which can be identified with special areas within the cerebral cortex. Let us consider first the areas representing action, which term we may select to describe the function of the motor areas. The motor areas of the human brain are all within the ascending frontal convolution. From above downwards are centers which control the movements of the leg, body, arm and face. (Figs. 145–147.)

Stimulation of this region will produce coördinated movements of the leg, trunk, arm and face. In the dog and lower animals these areas are not so sharply separated as they are in the higher apes or in a human being. Indeed in the human being these areas are even separated by unresponsive spaces or partitions. The areas may be stimulated by weak electrical currents directly applied. In contrast to the cerebellum only weak currents are required, even smaller than is needed to stimulate the underlying white matter after removal of the gray matter.

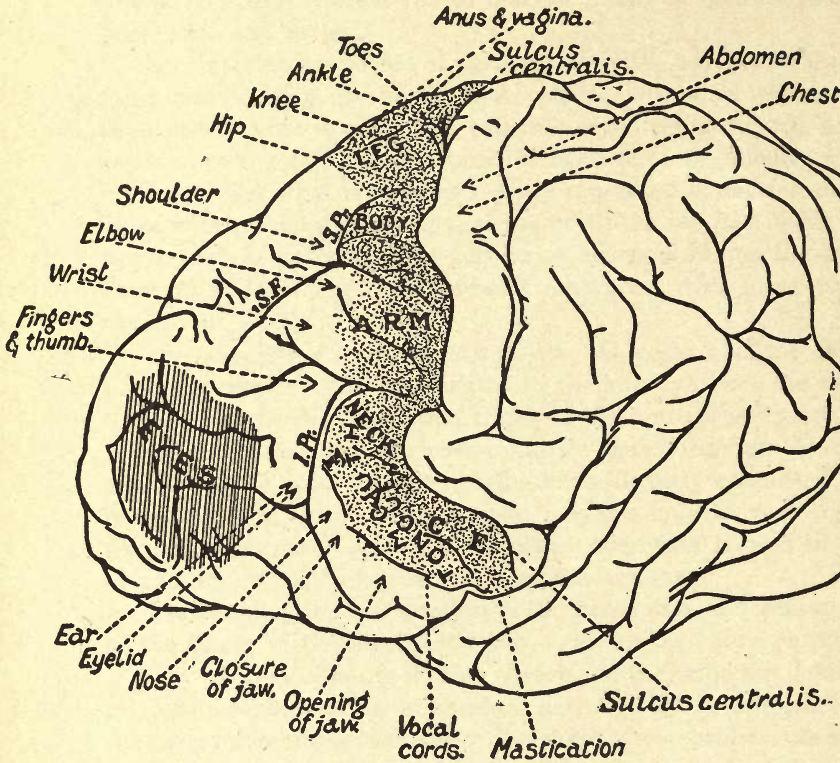


Fig. 145.—Brain of a chimpanzee (Troglodytes niger). Left hemisphere viewed from side and above so as to obtain as far as possible the configuration of the sulcus centralis area.

The figure involves, nevertheless, considerable foreshortening about the top and bottom of sulcus centralis. The extent of the "motor" area on the free surface of the hemisphere is indicated by the black stippling, which extends back to the sulcus centralis. Much of the "motor" area is hidden in sulci; for instance, the area extends into the sulc. centralis and the sulc. precentrales, also into occasional sulci which cross the precentral gyrus. The names printed large on the stippled area indicate the main regions of the "motor" area. The names printed small outside the brain indicate broadly by their pointing lines the relation topography of some of the chief subdivisions of the main regions of the "motor" cortex. But there exists much overlapping of the areas and of their subdivisions which the diagram does not attempt to indicate.

The shaded regions, marked "EYES," indicate in the frontal and occipital regions respectively the portions of cortex which, under faradization, yield conjugate movements of the eyeballs. But it is questionable whether these reactions sufficiently resemble those of the "motor" area to be included with them. They are therefore marked in vertical shading instead of stippling, as is the "motor" area. *S.F.*, superior precentral sulcus. *I.Pr.*, inferior precentral sulcus. (Sherrington.)

This fact demonstrates that the cerebral cortex itself and not the underlying white matter is being stimulated. The fact is further attested to by the absence of the power to stimulate the cortex after

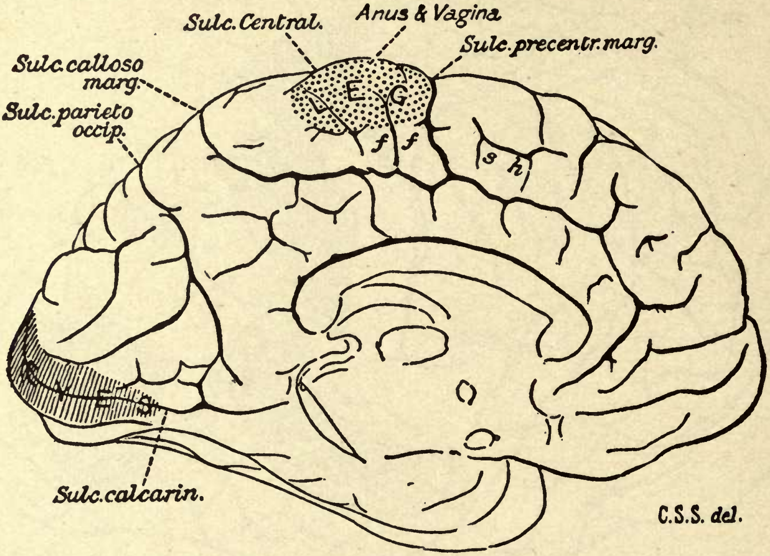


Fig. 146.—Brain of a chimpanzee (Troglodytes niger). Left hemisphere; mesial surface.

The extent of the "motor" area on the free surface of the hemisphere is indicated by the black stippling. On the stippled area *"LEG"* indicates that movements of the lower limb are directly represented in all the regions of the "motor" area visible from this aspect. Such mutual overlapping of the minuter sub-divisions exists in this area that the diagram does not attempt to exhibit them. The pointing line from *"Anus, etc."*, indicates broadly the position of the area whence perineal movements are primarily elicitable.

Sulc. central, central fissure; *Sulc. calcarin.,* calcarine fissure; *Sulc. parieto occip.,* parieto-occipital fissure; *Sulc. calloso marg.,* calloso-marginal fissure; *Sulc. precentr. marg.,* pre-central fissure.

The single italic letters mark spots whence, occasionally and irregularly, movements of the foot and leg (*ff*), of the shoulder and chest (*s*) and of the thumb and fingers (*h*) have been evoked by strong faradization. Similarly the shaded area marked *"EYES"* indicates a field of free surface of cortex which under faradization yields conjugate movements of the eyeballs. The conditions of obtainment of these reactions separates them from those characterizing the "motor" area. (Sherrington.)

it has been painted with cocaine or after the administration of chloral. Moreover the latent period after stimulating the gray matter is longer (.065 second) than when the white matter is directly stimulated (.045 second).

Characteristics of Movements Excited in the Cerebrum — By stimulation of the cortex coördinated movements, precisely similar to normal voluntary movements are elicited. This fact, of course, means that the normal tone of some muscles must be inhibited. This inhibition is absent during strychnine and tetanus poisoning so that

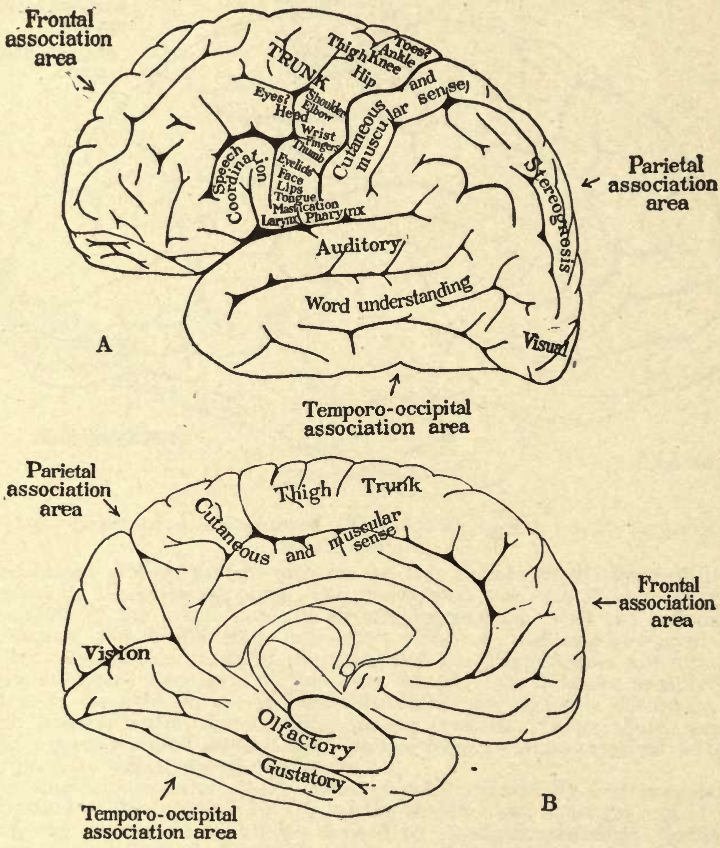


Fig. 147.—Diagrams suggesting the general motor, general and special sensory and the association areas of the convex and mesial surfaces of the cerebral hemisphere. (Morris.)

under the influence of these drugs only movements are obtained which represent those of the stronger set of muscles.

The part played by inhibition is well illustrated by the eye movements. When the convex surface of the inferior frontal convolution on the right side is stimulated both eyes turn toward the

left. This movement can only take place in the right eye by a simultaneous relaxation of the right external rectus and contraction of the right internal rectus and the reverse of these events in the left eye. After drying off all the muscles of the right eye except the external rectus the eye will be constantly turned outwards. The same strychnine applied here will cause a coincident relaxation of the right external rectus to permit of the eye returning to the middle line.

These experiments further illustrate the bilateral effect of certain unilateral external stimulation. In other words they illustrate the very pattern of coordination in the cortex as a purpose mechanism.

The Contrast and Interaction between the Control over Movement Exerted by the Cerebrum and Cerebellum.—The cerebellum also plays an important part in this coordination. Both organs are concerned in the maintenance of muscular tone and both are also concerned in coordination; but it is the special function of the cerebellum to maintain that constant tone which is essential to attitude while the cerebrum is especially for changing activity.

The cerebellum may be spoken of as the automatic organ of the brain in the influence which it exerts in response to sensory impulses, while the cerebrum is the voluntary agent; the cerebellum is the special center for continuous muscular contraction, while the cerebrum is the center for changing movements and may be played upon by other afferent impulses leading to voluntary contraction as well as by impulses through the proprioceptive system. The cerebellum may be viewed as a special reflex organ for proprioceptive impulses, where these impulses find a mechanical capability of passing on to the rest of the central nervous system as messages, resulting in coordinated tone without conscious control. In a large degree these effects may be seen from the cerebellum, but through the cerebellum which governs them unconsciously. The cerebellum, as a purposive organ, is related and adapted to the cerebrum for the production of coordinated movements (coordination). The cerebrum gives direction to the coordination of the voluntary changes of activity for which it alone is responsible.

The Difference in the Functions of the Cerebral Motor Areas in Man and in the Animal.—The effects of removal of the motor centers are very different in man and in animals even so high in the scale

left. This movement can only take place in the right eye by a simultaneous relaxation of the right external rectus and contraction of the right internal rectus and the reverse of these events in the left eye. After division of all the muscles of the right eye except the external rectus the eye will be constantly turned outward. The same stimulus applied now will cause a sufficient relaxation of the right external rectus to permit of the eye returning to the middle line.

These eye movements further illustrate the bilateral effect of certain unilateral cortical stimulation. In other words they illustrate that every movement originating in the cortex is a purpose movement.

The Contrast and Interaction between the Control over Movement Exerted by the Cerebrum and Cerebellum — The cerebellum also plays an important part in this same control. Both organs participate in the maintenance of muscular tone and both are able to do so by inhibition; but it is the special function of the cerebellum to maintain that constant tone which is essential to attitude while the cerebrum is responsible for changing activity.

The cerebellum may be spoken of as the automatic agent of the brain in the influence which it exerts in response to sensory impulses, while the cerebrum is the voluntary agent; the cerebellum is the special center for continuous muscular contraction, while the cerebrum is the center for changing movements and may be played upon by other afferent impulses leading to voluntary contraction as well as by impulses through the proprioceptive system. The cerebellum may be viewed as a special receiving organ for proprioceptive impulses, where these impulses find a mechanism capable of passing on to the rest of the central nervous system impulses, resulting in equilibrium and normal muscular tone. To a large degree these efferent impulses from the cerebellum pass through the cerebrum which in turn uses the cerebellar mechanism, as a prepared, accurately adjusted and sensitive mechanism for the production of an automatic unconscious coördination. The cerebrum gives direction to this coördination in the voluntary changes of activity for which it alone is responsible.

The Difference in the Functions of the Cerebral Motor Areas in Man and in the Animal — *Effects of removal of the motor centers* are very different in man and in animals even so high in the scale

of life as the dog. In the dog the first effect of the removal of the motor area is a very severe disturbance of the dog's power of movement. The muscles on the side opposite to the operation are much weaker. Recovery takes place after a few weeks, such complete recovery that the animal can be taught new movements involving the use of the affected limb.

In the monkey recovery is less complete. There is some permanent awkwardness and the immediate effect is one of absolute paralysis.

In man lesions of the motor area produce still more serious effects. There is absolute paralysis at first and only a very trivial amount of recovery, if the pathological condition can be removed. The amount of recovery will be inversely proportional to the amount of the motor area destroyed by the lesion or its operative removal.

These graded consequences of destruction of the motor area among animals and man are another illustration of the shifting of nervous activities as we ascend the scale of life from that region where they are necessitated by direct paths and few association tracts, activities that may be characterized by the word fateful, to a region where they are conditioned by any one set of a host of afferent impulses reaching the regions in question along any set of numerous association tracts which all together make consciousness possible.

In man there exists the possibility of a greater variation in response, or, in other language, a greater variety of movements. Actions become based on motive and new cerebral activities impossible in the animal are learned.

In man all must be learned at the expense of education. Man comes into the world with comparatively few laid down paths. For many years, as a reactive organism, he is far inferior to the lower animals. It is, however, only in virtue of this fact that in him a greater adaptation of action to intelligent needs becomes possible.

The Dependence of the Motor Area upon Different Impulses to it — In speaking of the motor area as a center for voluntary impulses we must not consider that the whole chain of events leading to a movement occurs in the motor area, or that all movements arise there. Like the cells in the anterior horns of the spinal cord the cells of the motor area are utilized as the last chain in a series of

[illegible]

The Receiving End of the Mechanism.—[illegible]

Fig. [illegible]

[illegible]

cerebral events and are played upon by other impulses participating in the complex mechanism which alone makes possible choice of action.

The Receiving End of the Mechanism — Having discussed the motor or discharging mechanism, let us turn to the other end of the chain of cerebral events, the receiving mechanism. Of first importance is that region of the brain which is most closely related to the perception of tactile and muscular sensibility. Many facts indicate that the ascending parietal convolution is the seat of

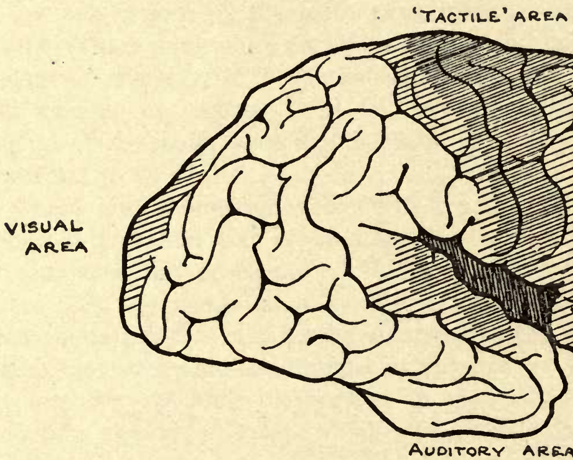


Fig. 148.—Outline drawing of the external surface of the hemisphere. Shaded portion represents the receptive area for tactile, auditory and visual sensations.

the direct perception of tactile and muscular sensibility. (Figs. 148 to 149.)

(1) Widespread lesions in the motor area will not only produce paralysis but more or less complete hemi-anesthesia.

(2) Lesions posterior to the fissure of Rolando including the posterior central convolution, the superior and inferior parietal, and the supramarginal convolutions are characterized by more pure disturbances of sensation.

(3) In the same manner certain more posterior lesions of this and the motor area of the brain, causing Jacksonian epilepsy, may be preceded by sensory aura. The sensory areas are less definitely located than the motor areas and may overlap and in part invade

the motor area. The sensory perceptions located in this region of the brain include the sense of pressure, of temperature and the muscular sense that is all sensations involved in stereognostic perception. The sense of pain is not included in this perception. It includes only those single perceptions which are needed for the perception of form, size and solidity. Lesions in region mentioned cause chiefly a disturbance of stereognostic perception, a symptom named astereognosis. With these lesions the sense of pain is little if at all affected. Even in tabes dorsalis there is atrophy of the posterior central convolution.

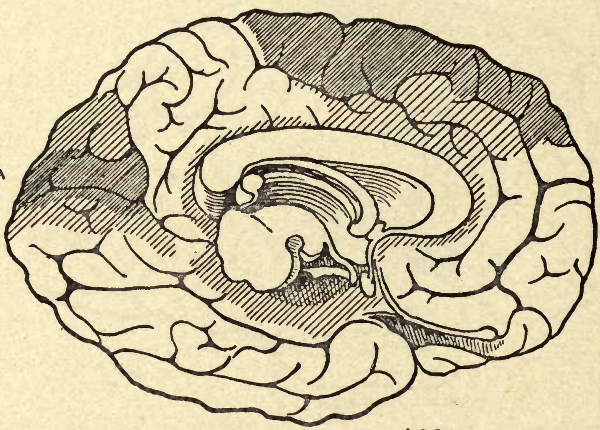


Fig. 149.—Inner surface of the same hemisphere.

The impulses of these sensations ascend in the mesial fillet to the optic thalamus and pass thence by a new set of fibers through the hinder limb of the internal capsule to the parietal region.

The thalamus, however, sends fibers to other portions of the brain. Cortical lesions of the central convolutions never produce complete hemianesthesia, so that while the posterior central or ascending parietal convolution is the chief cerebral receiving station for tactile and muscular sensations, widely separated other portions of the brain may participate in this function.

Visual Perception — This is located in the occipital lobe, in the cuneus and convolutions bordering the calcarine fissure. Very definite evidence exists in support of this fact.

(1) Lesions of one occipital lobe cause crossed hemianopia, i.e., blindness in the half of each retina which is opposite to that of the uninjured lobe. The [illegible] effect is explained by the manner in which the optic fibers cross in the optic chiasm.

(2) Stimulation of the occipital lobe of an animal causes the eyes to move toward the opposite side because of a revival of past visual sensations.

(3) The eyes roll away downward and to the opposite side if the upper part of the occipital lobe is stimulated and upward and to the opposite side if the lower portion of occipital lobe is stimulated.

(4) From the hinder end of the pulvinar and external geniculate body which receive the optic nerves, fibers arise which pass through the hinder end of the internal capsule and to the optic radiations (occipital lobe).

(5) Pathological lesions fully confirm these conclusions.

Perception of hearing.—Situated in the superior temporal convolution, but probably not entirely here.

(1) Destruction of the superior temporal convolution in monkeys gives marked disturbances, but not a complete disturbance of hearing.

(2) Bilateral lesions of the superior temporal convolution in man produce a varying degree of deafness.

(3) Stimulation of the superior temporal convolution with electric currents in monkeys pricks up the ears as if sounds were heard.

(4) From the auditory nucleus in the medulla fibers pass in the tegmentum and [illegible] by the [illegible] fillet to the inferior corpora quadrigemina. From this body [illegible] the internal geniculate body and thence over the hinder part of the internal capsule and [illegible] to the auditory radiations to the superior temporal convolutions. The fibers passing between the internal geniculate bodies [illegible] which form the posterior [illegible] of the optic radiation.

Smell and Taste Perception.—Located in the hippocampal gyrus [illegible] [illegible] the inner part of the temporal lobe [illegible] [illegible] surface of the temporal [illegible] [illegible] the sense of smell [illegible] [illegible] the connections are [illegible] [illegible] is only inferred [illegible] that the

(1) Excision of one occipital lobe causes crossed hemianopsia, *i.e.,* blindness in the half of each retina which is opposite to that of the extirpated lobe. This bilateral effect is explained by the manner in which the optic fibers cross in the optic chiasma.

(2) Stimulation of the occipital lobe in an animal causes the eyes to move toward the opposite side because of a revival of past visual sensations.

(3) The eyes will move downward and to the opposite side if the upper part of the occipital lobe is stimulated and upward and to the opposite side if the lower portion of occipital lobe is stimulated.

(4) From the hinder end of the pulvinar and external geniculate body which receive the optic nerves, fibers arise which pass through the hinder end of the internal capsule and, as the optic radiations, to occipital lobes.

(5) Pathological lesions fully confirm these conclusions.

Perception of hearing — Situated in the superior temporal convolution; but probably not entirely here.

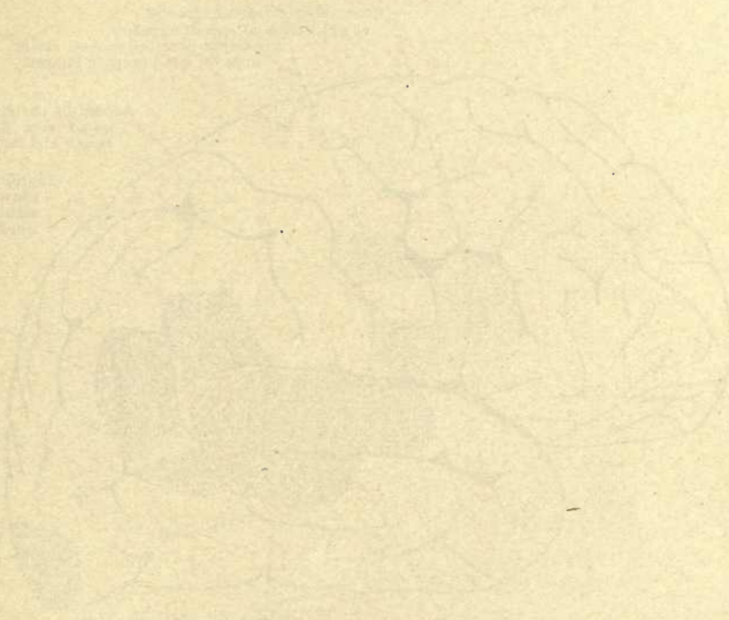
(1) Extirpation of the superior temporal convolution in monkeys produces marked disturbances, but not a complete disturbance of hearing.

(2) Cortical lesions of the superior temporal convolution in man produce varying degrees of deafness.

(3) Stimulation of the superior temporal convolutions will cause animals to prick up their ears as if sounds were heard.

(4) From the auditory nucleus in the medulla nerve fibers pass to the trapezium, and thence by the lateral fillet to the inferior corpora quadrigemina. From this body and the internal geniculate body they pass into the hinder parts of the internal capsule and thence as the auditory radiations to the superior temporal convolutions. The fibers from the two internal geniculate bodies decussate across the middle line in Guddens' commissure which form the posterior fibers of the optic chiasma.

Smell and Taste Perception is located in the hippocampal gyrus, the dentate convolution and in that portion of the limbic lobe known as the gyrus fornicatus which immediately borders the superior surface of the corpus callosum. Among animals the sense of smell is a far more important sense than in man. Its connections are, therefore, widespread. In man it is only natural to expect that the



same widespread connections should exist and, perhaps, be all the less well defined on account of the contemporaneous huge development of the rest of the brain and the corresponding disappearance of the acuteness of the perception of smell (see Fig. 147).

Electrical stimulation of the hippocampal convolution has caused movements of the lips and nostrils. Ablation experiments

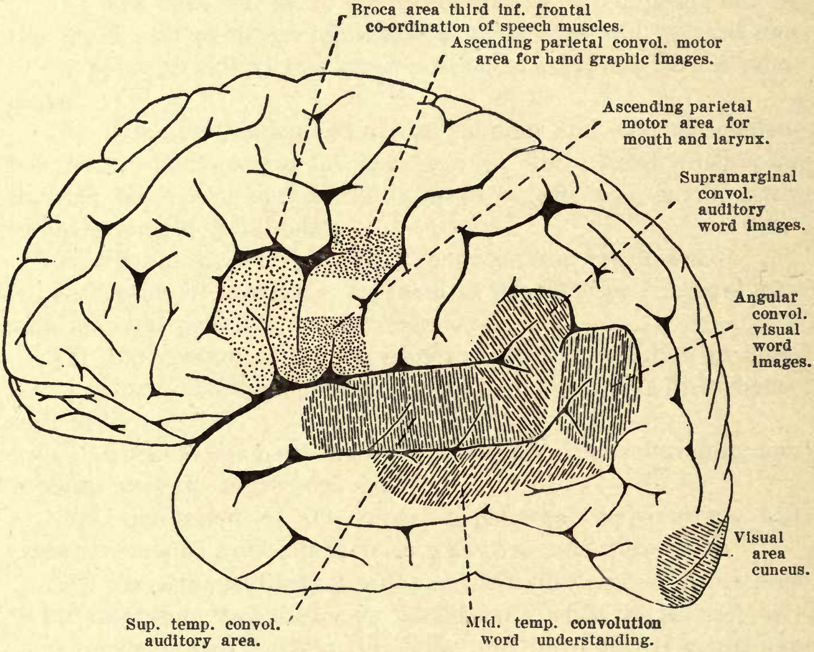


Fig. 150.—Convex surface of left cerebral hemisphere and diagrammatic presentation of the areas suggested as concerned with speech. (Morris.)

have not given much information. The most valuable information is to be derived from the connections in the lower animals. In addition to the portions of the brain which we have mentioned, the posterior part of the inferior surface of the frontal lobe and the olfactory lobe and the anterior commissure must be included.

Association Areas and the Significance of Association of Cerebral Impulses and Their Relation to Thought and Speech — The areas of the brain which we have identified with perception and action occupy a comparatively small amount of the cortex of the brain.

Inasmuch as the cerebral processes [illegible] more rapidly than [illegible] [illegible] and the [illegible] [illegible] in the [illegible] [illegible] [illegible]. [illegible]

[illegible] cerebral processes [illegible] of [illegible] variety of [illegible] of these [illegible] forms of [illegible] [illegible] of the [illegible] of the [illegible] [illegible]

The Integration of Experiences Made Possible by Speech. — These [illegible] make possible [illegible] and memory.

Aphasia. — In the development [illegible] [illegible]

The Varieties of Aphasia. — [illegible] [illegible] forms of aphasia have been described.

Motor Aphasia. — This form of aphasia has been described [illegible]

Inasmuch as the cerebral processes transpiring within these areas cannot be unraveled, they have been termed the *silent areas,* and as the living being rises in the scale of intelligence these areas become relatively larger. They make up by far the larger portion of man's brain.

When we attempt to analyze the cerebral processes accompanying a single combination of sensations and the infinite variety of cerebral processes representing the result of the influence of these sensations collectively, it is quite evident that even simple forms of cerebral activity are very intricate. Thinking is only possible because of man's power to quickly call into use, or in other words to associate, many portions of the brain which have to do with previous sensations. So intricate does this activity become that a large part of the advantage of the means for this association becomes lost without provision for cerebral short cuts. The association itself is primarily accomplished by connecting neurons and the process of association of impulses or a set of impulses which have been linked together as a unit (such a unit often constituting a concept or idea) is facilitated by the laying down of other fibers or even tracts which furnish short cuts and which make possible the more rapid revival of not only past perceptions as they happen to be related to a particular stimulus starting the cerebral activity, but also whole groups of perceptions, taken as a whole.

The Grouping of Perception Made Possible by Speech — These short cuts, therefore, make possible education and memory.

Speech — In the development of man the rapid association of groups of impulses constituting concepts has been greatly facilitated by the adoption of audible symbols for concepts. By this invention man has rendered possible, as a result of his greater power of association and his power of phonation, an almost indefinite enlargement of the power of reviving instantaneously past associations of great complexity. Upon this invention alone depends our power of intricate thinking.

The Varieties of Aphasia — Various disturbances of the power of speech demonstrate more closely the cerebral processes upon which it is based. A number of different forms of aphasia have been described.

(1) *Motor Aphasia* — This form of aphasia has been described as an inability to speak though the individual understands every-

[illegible] result in fits and [illegible] diminution of the intelligence. The motor aphasia has been for a long time associated with a lesion in the third left frontal convolution immediately anterior to the insertion of the ascending frontal convolution. This area has been named "Broca's area" after the man who first described its association with motor aphasia. The traditional conception of motor aphasia as a lesion in the third left frontal [illegible] right-handed people [illegible] has been so strongly attacked that few clinicians do not regard it untenable. Nevertheless the generalization will not [illegible] if it is applied to the complex character of all the [illegible] necessary to speech, centres of [illegible] in the cortex of the brain, and [illegible] the [illegible] localization of sensory aphasia with the area of Wernicke.

[illegible] in the [illegible] are the motor centres for the muscles of the larynx, for the majority of cases of motor aphasia are really a disease of the arteries, and upon autopsy are found to be associated with lesions in other localities, particularly at the [illegible] and the anterior portion of the internal capsule. No great ground exists for distinguishing between motor aphasia, when intelligence is unimpaired, and the type of aphasia described above as the word amnesia. The majority of cases described as motor aphasia are associated with impaired intelligence and belong to the second variety of aphasia.

(4) *Sensory Aphasia or Word-Deafness.*—This form of aphasia is associated with lesions in the supramarginal and angular gyri and posterior part of the second temporal convolutions. In this condition there may be no loss of power of speech, but there is invariably impaired intelligence and especially of the appreciation of spoken words. There may also be loss of power to recognize written words [illegible]. The major portion of this aphasia [illegible] is the inability to understand his own spoken words.

(5) *Agraphia.*—In this condition there is a pure impairment of the motor power of expression. It is generally associated with a lesion in the external capsule. [illegible] or speech without [illegible] is seldom seen unless intelligence is impaired.

Wernicke's area must be regarded as only one of the great association centres of the brain between various forms of perception, and between these and action. Lesions in them mean a limiting of intelligence, because the power of forming complex concepts is

thing which is said to him and suffers no impairment of his intelligence. This form of aphasia has been for a long time associated with a lesion in the third left frontal convolution immediately anterior to the lower end of the ascending frontal convolution. This area has been called Broca's area, after the man who first described the aphasia and its associated lesion. The traditional association of motor aphasia with a lesion in the third left (right-handed people) convolution has been so strong that few clinicians do not accept it outright. Nevertheless the association will not bear investigation. Theoretically it should not. The complex character of all the associations necessary to speech cannot be grouped in one center of the brain, and the same argument contradicts with equal force the too strict localization of sensory aphasia with the area of Wernicke.

Undoubtedly near Broca's area in the cortex are the motor centers for the muscles of the larynx, but the majority of cases of motor aphasia are really a species of anarthria, and upon autopsy are found to be associated with lesions in other locations particularly in the external capsule and the anterior portion of the internal capsule. No good ground exists for distinguishing between motor aphasia, when intelligence is unimpaired, and the type of aphasia described below by the word anarthria. The majority of cases described as motor aphasia are associated with impaired intelligence and belong in the second variety of aphasia.

(2) *Sensory Aphasia or Aphasia of Wernicke* — This form of aphasia is associated with lesions in the supra-marginal and angular gyri and posterior end of the second temporal convolutions. In this condition there may be limited power of speech, but there is impairment of intelligence and especially of the appreciation of spoken words. There may also be loss of power to recognize written words (*alexia*). The motor portion of this aphasia is due rather to the individual's inability to understand his own spoken words.

(3) *Anarthria* — In this condition there is a pure impairment of the motor powers of expression. It is generally associated with a lesion in the external capsule. Appreciation of speech written and spoken is perfect and intelligence is unaltered.

Wernicke's area must be regarded as only one of the great association centers of the brain between various forms of perception and between them and motion. Lesions in them mean a blunting of intelligence, because the power of forming complete concepts is

lacking though the individual may be in perfect possession of the general faculty. In true idiocy there is an impairment of the higher association centers located in the prefrontal region. The simpler concepts are probably formed but the power of combining these in a manner necessary for the processes involved in logical thought is lost. By means of the myelinization method Flechsig has been able to divide up the cerebral cortex into distinct areas. Eight of these belong to the regions which have been described as associated with the afferent and or primary projection areas of the cortex.

In the case of seven areas the function is uncertain. The areas do not possess either projection fibers or apparently association fibers.

Nineteen areas are provided with short association fibers. They may be termed intermediate areas.

Three areas possess longer association fibers. They may be termed the large and important association areas. One of these occupies the prefrontal region on both the internal and external surface of the cortex. The second occupies the 2nd and 3rd temporal convolutions and the third a large area on the external surface of the cortex, including the posterior portion of the supramarginal convolution and extending posteriorly to the visual perception area in the cuneus. Until comparatively recently the nuclei of gray matter grouped under the name of the corpus striatum and including the lenticular nucleus and the caudate nucleus were regarded as similar in function to the optic thalamus and like it to constitute merely relay stations for impulses on the way to and from the brain. After destroying these nuclei, however, degenerated fibers are found passing from them to the optic thalamus. These nuclei, therefore, send out efferent fibers to lower centers (thalamus). They are also known to receive fibers from the optic thalamus and the olfactory tracts. Such connections indicate that these nuclei are independent masses of gray matter capable of receiving afferent impulses from below and of sending out independent efferent impulses. They must be regarded as relay stations within the brain itself between the cortex and the lower thalamic centers.

In a series of animals representing an ascending scale of cerebral development, the corpus striatum occupies a relatively less important in cerebral activities. In birds, on the other hand, they

lacking though the individual may be in perfect possession of the logical faculty. In true insanity there is an impairment of the higher association centers located in the prefrontal region. The simpler concepts are perfectly formed but the power of grouping these in a manner necessary for the processes involved in logical thought is lost. By means of the myelinization method Flechsig has been able to divide up the cerebral cortex into some 36 areas. Eight of these belong to the regions which have been described as associated with the action end or primary projection areas of the cortex.

In the case of seven areas the function is uncertain. The areas do not possess either projection fibers or apparently association fibers.

Eighteen areas are provided with short association fibers. They may be termed intermediate areas.

Three areas possess long association fibers. They may be termed the large and important association areas. One of these occupies the prefrontal region on both the internal and external surface of the cortex. A second occupies the 2nd and 3rd temporal convolutions and the third a large area on the external surface of the cortex, including the posterior portion of the supramarginal convolution and extending posteriorly to the visual perception area in the cuneus. Until comparatively recently the nuclei of gray matter grouped under the name of the corpus striatum and including the lenticular nucleus and the caudate nucleus were regarded as similar in function to the optic thalamus and like it to constitute merely relay stations for impulses on the way to and from the brain. After destroying these nuclei, however, degenerated fibers are found passing from them to the optic thalamus. These nuclei, therefore, send out efferent fibers to lower cerebral nuclei. They are also known to receive fibers from the optic thalamus and the olfactory tracts. Such connections indicate that these nuclei are independent masses of gray matter capable of receiving afferent impulses from below and of sending out independent efferent impulses. They must be regarded as relay stations within the brain itself between the cortex and the lower thalamic centers.

In a series of animals representing an ascending scale of cerebral development the corpus striatum occupies a relatively less importance in cerebral activities. In birds, on the other hand, they

have their greatest development. It would appear that they represent then a divergent development in birds, taking over an increasing number of functions in them, while in mammals they are retrogressive, their functions being shifted to the pallidium or cerebral hemispheres. Stimulation of these nuclei produces no

Fig. 151.—Horizontal section through the right cerebral hemisphere at the level of the widest part of the lentiform nucleus. (Cunningham.)

movements. In the monkey their destruction is followed by no definite results. In man lesions in these bodies produce tremors in the execution of willed movements and an increased tonicity of the muscles, functions resembling those of the cerebellum.

Experimental evidence of the nature of the application of isolated heat and cold to the anterior part of the corpus striatum indicates that this portion of gray matter contains the chief thermo-

[illegible]

The Histological Structure of the Cortex. [illegible]

[illegible]

taxic center of the body. Cooling it, for instance, produces shivering and increased heat production in the body, while warming it produces the opposite effect.

The Histological Structure of the Cortex — The preceding localization of nervous function within the cerebral cortex is largely confirmed by a study of the histological structure of the cortex. The cortex consists of many layers of cells imbedded in a neuroglia supporting framework. As the Purkinje cells are characteristic of the cerebellum, so the pyramidal cell belongs peculiarly to the cerebral cortex.

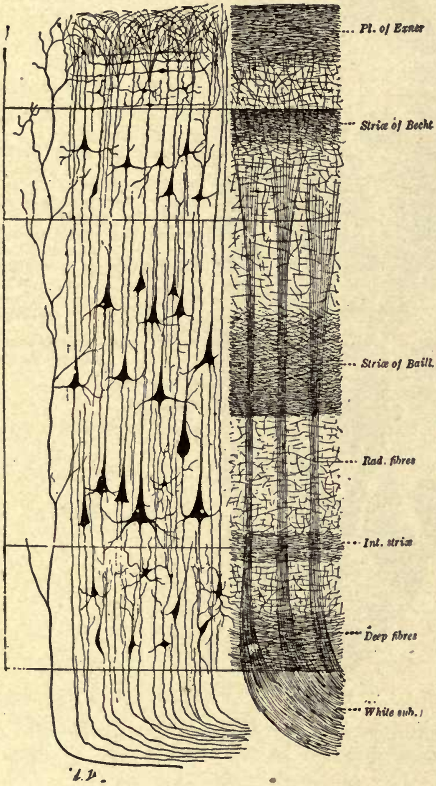


Fig. 152.—Cerebral cortex, diagrammatic section.

On the left, the cellular layers; on the right, systems of fibres; on the extreme left a sensory fibre is seen ascending; 1, 2, 3, 4, the four layers of cells; 2 and 3 representing pyramidal cells of differing size.

It is a cone-shaped or pear-shaped cell with one large apical dendrite which runs towards the surface to break up in the most superficial layers of the cortex into a number of branches. Dendrites are given off from the sides of the cell. The axon starts in the base of the cell and passes down into the white matter, giving off collaterals in its course.

Some fibers reach the corpus callosum, others the internal capsule, and others adjacent parts of the cortex.

There may be distinguished four or five layers of cells within the cortex. (Fig. 152.) (1) *Outer fiber lamina or molecular layer* contains few cells spindle-shaped the processes of which run parallel to the surface. The layer is mostly composed of the branching dendrites of the

[illegible]

[illegible] the [illegible] of the [illegible] and [illegible] are called [illegible]

[illegible] pyramidal cells [illegible] many types [illegible]

The fibers from the [illegible] cells of the brain [illegible] toward the [illegible] of the various layers [illegible]

[illegible] between the [illegible] layer and the pyramidal cell layer. It is called the outer line of [illegible]

[illegible] the inner line of [illegible]

[illegible]

cells of the deeper layers. (2) *Outer cell lamina or pyramidal cell layer.*

It contains three varieties of pyramidal cells arranged from without inwards into (a) small pyramidal cells, (b) medium pyramidal cells, (c) large pyramidal cells. (3) *Stellate cell layer or middle cell lamina,* as indicated, contains stellate-shaped cells. (4) *Inner fiber lamina,* composed of many nerve fibers and in certain portions of the brain, particularly the motor areas, this layer contains large solitary cells, the cells of Betz. (5) *The polymorphous cell layer* and inner cell lamina, containing cells of many types, but among which the pyramidal cells predominate. Some of the pyramidal cells are inverted, so to speak, their axons run to the surface. These are called cells of Marinotti. Other cells, Golgi cells, possess freely-branching axons ending near the cell.

The fibers from the white matter of the brain run toward the surface, giving off a rich meshwork of fibers to the various layers of gray matter. Other fibers run parallel to the surface and on the very surface of the brain. These fibers in some regions, especially the hippocampal region, are so well marked that they are termed the tangential fibers.

Another layer of tangential fibers is found between the molecular layer and the pyramidal cell layer. It is called the outer line of Baillance.

Internal to the granular layer is another layer of tangential fibers, the inner line of Baillance.

In the occipital region there is a special tangential layer running through the middle of the granular layer. It is called the line of Gennari.

Identification of Function by Means of Histological Detail—The thickness of these various layers furnish information as to the function of the various portions of the cerebral cortex.

In the ascending frontal convolution the cells of Betz are numerous and larger than in any other region. The pyramidal cell layer is also very thick.

In the visuo-sensory area the stellate cell layer or granular layer is thickest and the line of Gennari present.

In association areas, the parietal, temporal and frontal the outer cell layer or pyramidal cell layer is very thick. It is the most

[illegible] of vertebrates in these regions. These cells are therefore [illegible] with the higher functions of association.

In animals lower than man [illegible] of the cerebral [illegible] association. In lower animals, the rabbit, the [illegible] the [illegible] of the [illegible].

We may, therefore, [illegible] the cells of [illegible] the [illegible] of cells [illegible] the [illegible] of the [illegible].

When the [illegible] are [illegible] either because of the [illegible] the cells are less numerous in the region [illegible] the [illegible] functions.

Time of [illegible] Cerebral Activities.—The time of the various reactions in which the brain is concerned is of interest. They may be [illegible] and [illegible] the [illegible] of the [illegible] and [illegible] the [illegible] of the patient.

The time for the reaction to [illegible] is 150 to 200 of a second [illegible] 120 to 150 second [illegible] 180 to 200 second.

The [illegible] by [illegible] of the [illegible] by the [illegible].

[illegible] by [illegible] or by the [illegible] strength of the [illegible].

THE SYMPATHETIC NERVOUS SYSTEM

In addition to [illegible] from the central nervous system to the various portions of the body [illegible]. First, those conveying motor impulses from the spinal cord and [illegible] those conveying sensory impulses. In addition to these nerves there is another [illegible] with the cranial nerves and the [illegible] of the spinal [illegible] which [illegible] impulses [illegible] to the blood vessels and glands.

[illegible] sympathetic [illegible].

[illegible] with peripheral

marked feature of sections in these regions. These cells, therefore, have to do with the higher functions of association.

In animals lower than man, the ape and dog, less of the brain is occupied with areas possessing the histological structure identified with association. In still lower animals, the rabbit, the polymorphous layer is three times the thickness of the pyramidal layer.

We may, therefore, assign to the cells of Betz motor function, to the pyramidal cells associative functions, and to the polymorphous cells functions concerned in the getting of food and the gratification of the various sensuous instincts.

When the cerebral activities are deficient either because of disease or congenital defects, the cells are less numerous in the regions controlling the deficient functions.

Time of Certain Cerebral Activities — The time of the various reactions in which the brain is concerned is of interest. They may be recorded by an electrical apparatus which marks the moment of the application of any stimulus and, through a shunt circuit, the voluntary reaction of the patient.

The time for the reaction to sight stimuli is .186 to .222 of a second; to hearing .115 to .182 second; to electrical stimulation of skin .117 to .201 second.

The time may be lengthened .006 second by fatigue of the reaction, or by a dilemma, involving choice by the individual.

It may be shortened by practice, or by increase in strength of the stimulus.

THE SYMPATHETIC NERVOUS SYSTEM

The nerves passing from the central nervous system to the various portions of the body may be divided into two different classes. First those conveying motor impulses from the spinal cord and brain and those returning sensory impulses. In addition to these nerves there is another class of nerves issuing with the cranial nerves and the anterior and posterior roots of the spinal nerves which convey afferent impulses from and efferent impulses to the blood vessels and viscera.

Briefly, they supply smooth muscle and glandular tissue.

The nerves of this second class are connected with peripheral

ganglia and pass to the [illegible] ganglia [illegible]. All these fibers are preganglionic and part of the [illegible] system.

[illegible] the sympathetic nervous system may be divided into the cranial or [illegible] portion [illegible] and the sacral portion of the [illegible] system. [illegible] the [illegible] nerves of the [illegible] and [illegible] visceral [illegible] the visceral nervous system.

The sympathetic fibers of the third cranial nerve pass with the third nerve to the orbit. Leaving the branch of the third nerve which supplies the inferior oblique muscle, they enter the ciliary ganglion. From this ganglion the fibers [illegible] as short ciliary nerves, after [illegible] the [illegible] to the sphincter pupillae muscle and the ciliary muscle.

The sympathetic fibers of the 7th cranial nerve are contained in the nerve of Wrisberg. This nerve also contains fibers of taste from the tongue. The fibers belonging to the visceral system, however, leave the [illegible] nerve by the chorda tympani and later join the lingual nerve and with this pass to the submaxillary ganglion. From this ganglion [illegible] fibers [illegible] to the submaxillary and sublingual salivary glands. The [illegible] also [illegible] fibers to the sphenopalatine ganglion from which [illegible] fibers supply the mucous membranes of the nose and soft palate and upper part of the pharynx.

The sympathetic fibers of the 9th nerve pass to the otic ganglion. From this ganglion [illegible] fibers pass to the parotid gland and supply it with [illegible] fibers.

Practically all of the vagus nerve may be regarded as belonging to the visceral system. [illegible] ganglia [illegible]. [illegible] of the heart [illegible] nerve [illegible] fibers [illegible] pulmonary [illegible] fibers to the [illegible] and secretory fibers to the stomach and pancreas.

Sympathetic Fibers of the Sacral Nerves.—Each sacral nerve [illegible] fibers which [illegible] the formation of the visceral system. They [illegible] ganglia [illegible] small [illegible]. They leave the anterior [illegible]

ganglia and differ histologically from other nerves. All these facts warrant their classification as a separate system.

It is called the vegetative nervous system, and may be divided into the autonomic or cranial portion of the vegetative nervous system and the spinal portion or the sympathetic nervous system.

In contradistinction from it we may call the other nerves of the body those innervating skeletal muscle and returning sensory impulses the somatic nervous system.

The vegetative nerves of the third cranial nerve pass with the third nerve to the orbit. Leaving the branch of the third nerve which supplies the inferior oblique muscle, they enter the lenticular ganglion. From this ganglion their axons are continued, after interruption, as the short ciliary nerves to the sphincter pupili muscle and the ciliary muscles.

The vegetative nerves of the 7th cranial nerve are contained in the nerve of Wrisberg. This nerve also contains fibers of taste from the tongue. The fibers belonging to the vegetative system, however, leave the 7th nerve as the chorda tympani and later join the lingual nerve and with this pass to the submaxillary ganglion. From this ganglion it supplies dilator fibers and secretory fibers to the submaxillary and sublingual salivary glands. The chorda tympani also sends fibers to the sphenopalatine ganglion from which postganglionic fibers supply the mucous membrane of the nose and soft palate and upper part of the pharynx.

The vegetative fibers of the 9th nerve pass to the otic ganglion. From this ganglion its post ganglionic fibers pass to the parotid gland and supply it with vaso-dilator and secretory fibers.

Practically all of the vagus nerve may be regarded as belonging to the visceral system. The jugular ganglion represents its ganglion cell station. The ganglion of the trunk of the vagus probably corresponds to a posterior spinal ganglion and is connected with afferent nerves of the vagus nerve only. As has already been mentioned, it supplies motor fibers to the alimentary tract as far as the ileocolic sphincter, inhibitory fibers to the heart, motor fibers to the bronchi and secretory fibers to the stomach and pancreas.

Sympathetic Fibers of the Spinal Nerves — Each spinal nerve gives off fibers which participate in the formation of the visceral system. They are represented in the anterior nerve roots by the small medullated fibers. (Fig. 153.) These leave the anterior divi-

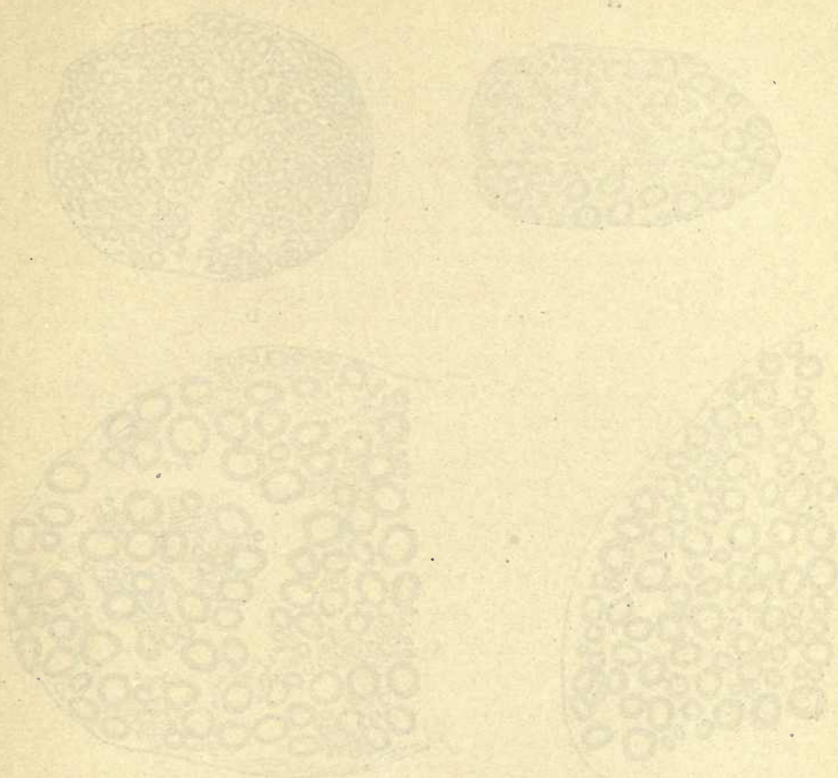


Fig. [illegible] Showing the same part of the roots of [illegible] nerves of the dog, [illegible]

[illegible]

A, from one of the upper roots of the [illegible]

B, a portion of the [illegible]

C, from the last [illegible]

D, from the second thoracic [illegible]

[illegible]

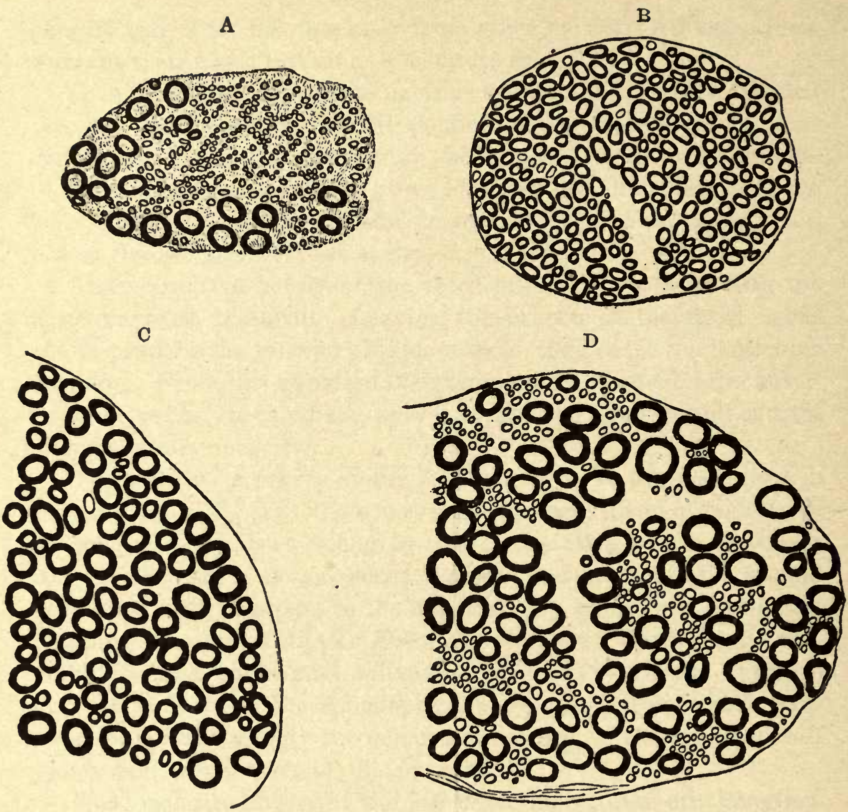


Fig. 153.—Sections across parts of the roots of various nerves of the dog, to show the variations in size of their constituent fibres. (Quain.)

(The nerves were stained with osmic acid, and the sections are all drawn to one scale.)

A, from one of the upper roots of the accessory.
B, a rootlet of the hypoglossal.
C, from the first cervical ventral root.
D, from the second thoracic ventral root.

sion of the spinal nerves and run to one set of ganglia but terminate in one of two sets of ganglia. One of these sets of ganglia forms a chain of ganglia lying close to the vertebral column. In general there may be said to be one ganglion for each vertebral segment of the column in the thoracic and lumbar region and three ganglia for the cervical region.

The second series of ganglia are the cardiac plexus at the root

of the lungs and base of the heart, the solar plexus around the celiac axis, the superior and inferior mesenteric plexuses around the origin of the superior and inferior mesenteric arteries, the hypogastric and pelvic plexuses in front of the body of the 5th lumbar vertebra.

We have still the spinal ganglia, the lateral series of ganglia and the ganglia in the large plexuses around the great vessels (the collateral ganglia). Another set of plexuses might be mentioned which exist in the walls of the viscera. They are the plexuses of Meissner and Auerbach. Though called terminal ganglia they contain no gan-

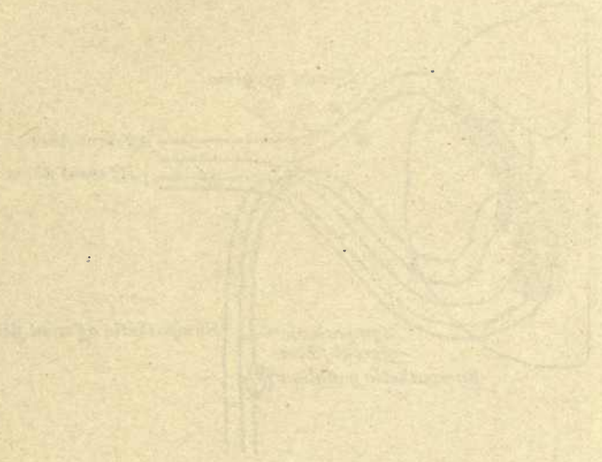


Fig. 151.—Plan of sympathetic nerve (spinal nerve, ganglia).

glion cells and are rather to be viewed as sites of intermingling of nerve fibers which suffer no interruption in passing through them. All of the sympathetic nerves leaving the cerebro-spinal axis of the sympathetic system pass to the spinal or lateral ganglia; as they are medullated they are called white rami communicantes. Some of them end in a terminal arborization around the cells of these ganglia; others pass through these ganglia without interruption to end around cells of the collateral series of ganglia. All these nerve fibers are called preganglionic nerve fibers. From the cells around which these preganglionic fibers end nerves are given off which are non-medullated and are called postganglionic fibers. (Figs. 151 and 152.)

Each sympathetic nerve has more than one of these interruptions

of the lung and base of the heart, the solar plexus around the celiac axis, the superior and inferior mesenteric plexuses around the origin of the superior and inferior mesenteric arteries, the hypogastric and pelvic plexuses, in front of the body of the 5th lumbar vertebra.

We may call the spinal ganglia the lateral series of ganglia and the ganglia in the large plexuses around the great vessels the collateral ganglia. Another set of plexuses more distal still, exists in the walls of the intestines. They are the plexuses of Meissner and Auerbach. Though called terminal ganglia they contain no ganglion cells and are rather to be viewed as sites of interlacing of nerve fibers which suffer no interruption in passing through them.

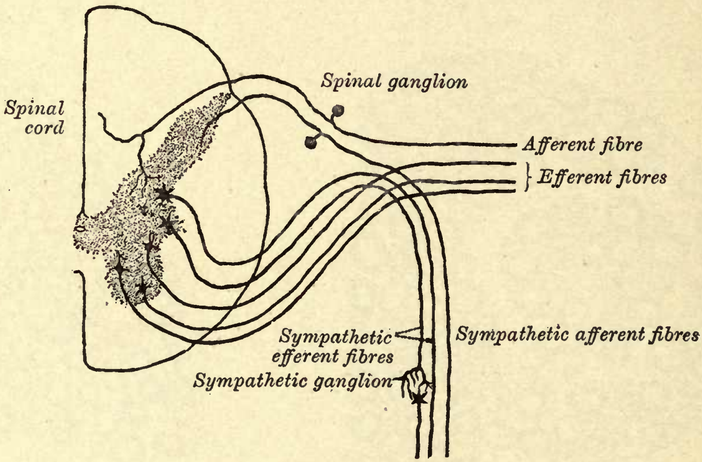


Fig. 154.—Plan of construction of a typical spinal nerve. (Quain.)

All of the sympathetic nerves leaving the anterior division of the spinal nerves pass to the spinal or lateral ganglia. As they are medullated they are called white rami communicantes. Some of them end in a terminal arborization around the cells of these ganglia; others pass through these ganglia without interruption to end around cells in the collateral series of ganglia. All these nerve fibers are called preganglionic nerve fibers. From the cells around which these preganglionic fibers end axons are given off which are non-medullated and are called post-ganglionic fibers. (Figs. 154 and 155.)

No sympathetic nerve has more than one of these interruptions

between its origin and destination. Many of the axons of the cells in the spinal ganglion run back from the ganglion to an anterior spinal nerve, of a different level, bend around again to be distributed with the fibers of such an anterior or posterior spinal nerve.

As they pass, therefore, between the ganglia and the spinal nerves they are also called rami communicantes, and because they are not medullated they are called gray rami communicantes.

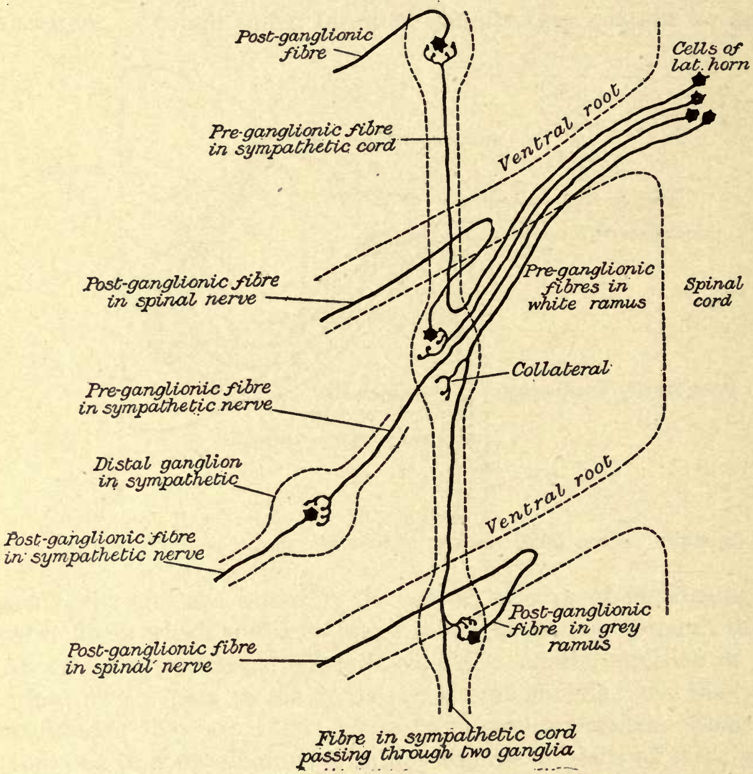


Fig. 155.—Diagram of sympathetic. (Quain.)

Each gray ramus communicans is distributed to only an area of the body which corresponds to the level at which it is given off.

A white ramus, on the other hand, may run a long distance before it terminates around a ganglionic cell from which its post-ganglionic fiber is given off. Stimulation of one white ramus will cause impulses in several gray rami.

The spinal ganglia of the upper three cervical nerves pass to the superior cervical sympathetic ganglion. Its branches of distribution are to plexuses around the carotid arteries and their branches.

It sends branches to the tympanum and to the Vidian nerve and to the Gasserian ganglion. Many fibers reach the superior cervical ganglion from the first five dorsal nerves. These fibers reach it after first passing through the dorsal spinal ganglia. They represent some of the white rami which have long preganglionic fibers, for their ganglionic cells are in the superior cervical ganglion. They convey the following impulses:

1. Vaso-constrictor impulses to blood vessels,
2. Dilator impulses to the pupil,
3. Secretory (trophic?) impulses to the salivary and sweat glands,
4. Vaso-dilator fibers to the lower lip and pharynx.

The same five dorsal nerves send fibers to the stellate ganglion, a large ganglion beneath the origin of the subclavian artery. It communicates by two cords which surround the subclavian artery with the inferior cervical ganglion of the sympathetic. The ring around the subclavian is called the ansa Vienssens. The inferior cervical ganglion of the sympathetic is placed between the superior and middle cervical ganglion above, with which it is also connected by two cords, and the stellate ganglion below.

From the cell stations of these fibers in the stellate ganglion post-ganglionic fibers of the upper dorsal nerves are given off to the heart.

They convey accelerator and augmentor impulses to the heart.

Each spinal ganglion is not only connected with the anterior spinal nerve by a gray and a white ramus but also with the ganglia above and below it by two connecting cords.

The upper limbs are supplied by nerves coming from the 4th to the 11th dorsal ganglia.

They convey:

1. Vaso-constrictor impulses to the blood vessels of the limbs,
2. Secretory fibers to the sweat glands.

The lower limbs are supplied by branches of the 11th dorsal to the third lumbar ganglion.

They convey:

1. Vaso-constrictor impulses to the vessels of the lower limb,

2. Secretory impulses to the sweat glands of the lower limb.

From the lower 6 dorsal and upper 3 to 4 lumbar ganglia fibers pass to the abdominal viscera.

They convey:

1. Vaso-constrictor fibers to the vessels of the stomach and small intestines, the kidney and spleen,

2. Probably vaso-dilator fibers as well,

3. Muscular inhibitory impulses to the stomach and small intestines,

4. Motor fibers for the ileocolic sphincter.

Nerves from the lower dorsal and upper 3 to 4 lumbar nerves pass to the pelvic plexus in two strong cords running as the hypogastric nerves from the inferior mesenteric plexus to the pelvic plexus.

They convey:

1. Vaso-constrictor impulses to the vessels of the viscera,

2. Inhibitory impulses to the colon,

3. Both motor and inhibitory impulses to the bladder,

4. Motor fibers to the retractor penis,

5. Motor fibers to the uterus and vagina.

Besides the autonomic fibers passing in the hypogastric nerves from the inferior mesenteric plexus to the pelvic plexus, the anterior branches of the second to the fourth sacral nerves furnish branches of autonomic fibers which, without making connections with any lateral ganglia, unite to form on each side the nervus Erigens. This nerve passes directly to the pelvic plexus in which its fibers suffer interruption.

They convey:

1. Motor impulses to the bladder, descending colon and rectum,

2. Vaso-motor impulses to the vessels of the pelvic viscera,

3. Inhibitory fibers to the sphincter of the bladder,

4. Dilator fibers to the vessels of the penis and inhibitory fibers to the retractor penis.

QUESTIONS AND ANSWERS

Pages 4–8

Q. What is the function which the nervous system has been developed to perform?

A. To make possible the rapid transmission between distant portions of the body of changes in the environment of groups of cells.

Q. What important stages in the development of a central nervous system are represented by the nervous systems of invertebrates?

A. The peripherally placed nervous system of a hydra in which there is but slight difference between the protective surface epithelial cell and the specialized sensitive and conductive epithelial cell, and in which the sensitive cell, the conductive portion and contractile tissue constitute one cell. (*Page 4.*)

The peripherally placed nervous system of the jellyfish in which the conductive tissue forms a ring about the periphery of the animal, separated from the surface epithelium and contractive tissue but connected to both and to different portions of itself by its own fiberlike processes. (*Page 8.*)

The centrally placed nervous system of the worm, and of the still more advanced crayfish: in both the cells of the conductive tissue are centrally placed, thus facilitating communication between different portions of itself and occupying the most efficient position for rapid communication with any portion of the periphery. In the more advanced crayfish there is a special development of the fore part of the central chain of nerve tissue, thus facilitating a quick appreciation of changes of the environment in the direction in which the animal moves. (*Page 12.*)

Page 14

Q. How is the nervous system of mammals developed from the cells of the embryo?

A. By the infolding of the epiblast, corresponding to the dorsum of that group of cells of embryo from which all this tissue of the fœtus are developed, there is formed the neural canal, and on each side a depressed cord of cells. By a differentiation of the cells lining the canal and forming the cord the primitive spongioblasts and neuroblasts are formed. Both these develop processes. The spongioblasts with their processes form the neuroglia or supporting tissue of the nervous system. The neuroblasts of the neural canal form nerve cells and their processes the motor nerves. These grow out into the body of the embryo and form connections with every active tissue. The neuroblasts of the lateral cords of cells develop into the nerve cells of the sensory ganglia. They develop two processes, one forming peripheral connections with the various specialized sensitive cells of the body, and the other growing centrally among the cells developing from the neural canal to participate in the formation of central synapses.

Page [illegible]

Q. Describe a neuron.
A. A neuron consists of a nerve cell and its processes. A nerve cell possesses the following parts: See text.

A nerve has the following structure: See text.

Page [illegible]

Q. Describe the different peripheral endings of nerves.
A. See text; also divide into sensory and motor nerve endings.

Page [illegible]

Q. Classify nerves.
A. See text.

Page [illegible]

Q. Discuss the method of measuring the velocity of nerve impulses for both motor and sensory nerves.
A. See text.

Q. In which direction does a nerve impulse travel?
A. In both directions from the stimulated point.

Page [illegible]

Q. Is there any liberation of energy caused by the passage of a nerve impulse. How much and how is it estimated?
A. A very small amount, not enough to be indicated by its transformation into heat, but only by the consumption of oxygen.

Page [illegible]

Q. What is the demarcation current?
A. The current carried in a nerve by the demarcating changes following injury to the nerve.

Q. What is the current of action?
A. The current which always accompanies the passage of a nerve impulse.

Q. In a specific nerve preparation in what order do the tissues become fatigued?
A. Motor end plate, muscle. The nerve is not known to become fatigued.

Page [illegible]

Q. What is summation?
A. The reaction evoked by the combined effect of several subliminal stimuli following each other at the proper frequency interval.

Q. What is the refractory period?
A. The period following an excitation during which the nerve remains incapable of reacting to a second stimulus.

Page 34

Q. Describe a neuron.

A. A neuron consists of a nerve cell and its processes. A nerve cell possesses the following parts: See text.

A nerve has the following structure: See text.

Page 54

Q. Describe the different peripheral endings of nerves.

A. See text, and divide into sensory and motor nerve endings.

Page 72

Q. Classify nerves.

A. See text.

Page 74

Q. Describe the method of measuring the velocity of nerve impulses for both motor and sensory nerves.

A. See text.

Q. In what direction does a nerve impulse travel?

A. In both directions from the stimulated point.

Page 76

Q. Is there any expenditure of energy caused by the passage of a nerve impulse, how much and how is it estimated?

A. A very small amount, not enough to be indicated by its transformation into heat, but only by the consumption of oxygen.

Page 78

Q. What is the demarcation current?

A. The current excited in a nerve by the degenerating changes following injury to the nerve.

Q. What is the current of action?

A. The current which always accompanies the passage of a nerve impulse.

Q. In a muscle nerve preparation in what order do the tissues become fatigued?

A. Motor end plate, muscle. The nerve is not known to become fatigued.

Page 84

Q. What is summation?

A. The reaction evoked by the combined effect of several sub-minimal stimuli following each other at the proper favorable interval.

Q. What is the refractory period?

A. The period following an excitation during which the nerve remains incapable of response to a second stimulus.

THE NERVOUS SYSTEM

Page 88

Q. At what electrode does excitation of a nerve by an electrical current take place?

A. At the cathode at the make, and anode at the break.

Q. What changes in degrees of excitability do these special sites of excitation undergo and what names are given to these changes?

A. They indicate changes in excitability which are proportional to the current strength; that change occurring at the cathode being named catelectrotonus, and at the anode, anelectrotonus, so that the coming in of the one and passing off of the other is what causes excitation.

Page 90

Q. How much of the nerve may be involved in anelectrotonus or catelectrotonus?

A. The greater the strength of the current the greater the length of the nerve which is in anelectrotonus, the remainder of the nerve being in catelectrotonus.

Q. What effect do the facts expressed in the last answer have upon the passage of the nerve impulse and what name is given to the phenomenon?

A. The nerve impulse may be blocked at the anode by a high degree of anelectrotonus or at the cathode by a sudden drop from a very high state of catelectrotonus to a very low state of catelectrotonus. The phenomena result in a response to stimulation which is different for different strengths of the current used, and this fact is called Pflüger's law.

Page 94

Q. What is the order of strength of contraction in the human being when the electrode must be applied on the surface of the skin at a distance from the nerve, and why is this order different from that order to be expected when the electrodes are applied directly to the nerves according to Pflüger's law?

A. 1. See text for order.
2. Because there is a greater strength of current, due to the diffusion of the lines of force between the electrodes, in that portion of the nerve which is nearest to the stimulating electrode.

Page 98

Q. What is the current of polarization and to what is it due?

A. The current of polarization is a current independent of vital changes occurring in an electrically stimulated nerve and is due to the difference in potential which appears upon the collection of ions about the electrodes and bearing an opposite charge to the electrodes. These ions arise in the electrolyte of the nerve sheath and the phenomenon is common to any electrolyte carrying a current.

Page 100

Q. What are the conditions affecting the excitatory effect in an electrically stimulated nerve?

A. 1. The rate of change in the make or break. There is an optimal rate of change.
2. The intensity of the current. There is an optimal intensity.

Page 86

Q. At what electrode does excitation of a nerve by an electrical current take place?

A. At the cathode at the make, and anode at the break.

Q. What changes in degrees of excitability do these special sites of excitation indicate and what names are made use of to express such changes?

A. They indicate changes in excitability which are proportional to the response evoked, that change occurring at the cathode being named cathelectrotones, and at the anode, anelectrotones, so that the development of the one and passing off of the other is what causes excitation.

Page 90

Q. How much of the nerve may be involved in anelectrotones or cathelectrotones?

A. The greater the strength of the current the greater the length of the nerve which is in anelectrotonus, the remainder of the nerve being in catelectrotonus.

Q. What effect do the facts expressed in the last answer have upon the passage of the nerve impulse and what name is given to the phenomenon?

A. The nerve impulse may be blocked at the anode by a high degree of anelectrotones or at the cathode by a swing back from a very high state of cathelectrotones to a very low state of cathelectrotones. The phenomena result in a response to stimulation which is different for different strengths of the current used, and this fact is called Pflüger's law.

Page 94

Q. What is the order of strength of contraction in the human being when the electrode must be applied on the surface of the skin at a distance from the nerve, and why is this order different from that order to be expected when the electrodes are applied directly to the nerves according to Pflüger's law?

A. 1. See text for order.

2. Because there is a greater strength of current, due to convergence of the lines of force between the electrodes, in that portion of the nerve which is nearest to the stimulating electrode.

Page 96

Q. What is the current of polarization and to what is it due?

A. The current of polarization is a current independent of vital changes occurring in an electrically stimulated nerve, and is due to the difference in potential which depends upon the collection of ions upon the electrodes and bearing an opposite charge to the electrodes. These ions arise in the electrolyte of the nerve sheath, and the phenomenon is common to any electrolyte carrying a current.

Page 100

Q. What are the conditions affecting the excitatory effect in an electrically stimulated nerve?

A. 1. The rate of change in the make or break. There is an optional rate of change.

2. The intensity of the current. There is an optional intensity.

3. The direction of the current. There is an optional direction. Thus conduction is different than nerve, motor and glide and sensory.
4. The Susceptibility. Narcosis, the power of narcotics to reduce its irritability.

Page 169

Q. In what direction may an impulse pass across a motor end plate?
A. It is the same in all synapses, only in the normal direction.

Page 170

Q. Describe the gross anatomy of the spinal cord.
A. See text.

Page 176

Q. What are the groups of nerve cells in the gray matter?
A. 1. Anterior horn cells. The motor cells.
2. Small cells in the lateral portion of the base of the anterior horn. The motor cells of the sympathetic nerves.
3. Cells in the inferior portion of the base of the posterior horn (Clarke's column), the axones of which form the direct lateral cerebellar tract.
4. Cells of the posterior horn, many of which are receiving cells of fibers of the posterior nerve roots and others association cells.

Page 180

Q. What are some of the methods of tracing the systems of neurones?
A. The Degeneration Method. See text for explanation.
The Wallerian Method. See text for explanation.

Page 182

Q. What is the termination of the fibers of the posterior nerve roots?
A. There are 3 sets of fibers. These fibers go into:
1. Lissauer's columns.
2. The columns of Goll and Burdach.
3. The fibers ending in the cells of the posterior horn, from which impulses are carried onward to the adjacent lateral column of the opposite side, to the anterior horn of same side, to posterior horn of opposite side, to Clarke's columns of cells, to small cells of lateral horn.

Page 186

Q. What are the descending spinal tracts?
A. See text.

Page 188

Q. What are the ascending spinal tracts?
A. See text.

Page 192

Q. What sensory impulses are carried by the various ascending tracts?
A. See text.

3. The duration of the current. There is an optional duration. This duration is different for nerve, motor end plate and muscle.
4. The temperature. Warming the nerve of mammal increases its irritability.

Page 104

Q. In what direction may an impulse pass across a motor end plate?
A. As is the case in all synapses, only in the normal direction.

Page 110

Q. Describe the gross anatomy of the spinal cord.
A. See text.

Page 116

Q. What are the groups of nerve cells in the gray matter?
A. 1. Anterior horn cells. The motor cells.
2. Small cells in the lateral portion of the base of the anterior horn, the motor cells of the sympathetic nerves.
3. Cells in the lateral portion of the base of the posterior horn, Clarke's column, the axons of which form the dorso-lateral cerebellar tract.
4. Cells of the posterior horn, many of which are receiving cells of fibers of the posterior nerve roots, and others association cells.

Page 120

Q. What are some of the methods of tracing the systems of neurons?
A. The Myelination Method. See text for explanation.
The Wallerian Method. See text for explanation.

Page 126

Q. What is the termination of the fibers of the posterior nerve roots?
A. There are 5 sets of fibers: those forming
1. Lissauer's column.
2. The columns of Goll and Burdach.
3. The fibers ending in the cells of the posterior horn, from which impulses are carried onward to the anterior lateral column of the opposite side, to the anterior horn of same side, to posterior horn of opposite side, to Clarke's columns of cells, to small cells of lateral horn.

Page 136

Q. What are the descending spinal tracts?
A. See text.

Page 140

Q. What are the ascending spinal tracts?
A. See text.

Page 142

Q. What sensory impulses are carried by the various ascending tracts?
A. See text.

Page 144

Q. What are the symptoms of unilateral section of the spinal cord?
A. See text.

Q. How may the spinal functions be studied to the best advantage and why?

A. By dividing the cord from the brain, because the functions of the cord will then be undisturbed by impulses from the brain.

Page 146

Q. What condition is induced by separation of the cord from the brain and what are the symptoms?

A. 1. Spinal shock.
2. Permanent loss of sensation and of voluntary motion below level of lesion.
3. Temporary loss of muscular tone, of vascular tone and of reflex response.

Q. To what are the symptoms of spinal shock due?

A. The permanent symptoms are due to division of the paths of sensory perception and voluntary motor impulses. The temporary symptoms are due to the division of paths through which, under normal conditions, impulses responsible for both vascular and skeletal tone are constantly passing. These paths include in part ascending tracts.

Page 151

Q. Define reflex action, explain its mechanism, and illustrate by named reflexes.

A. A reflex action is any motor response produced by a sensory stimulus. It involves an afferent limb or sensory neuron, conveying the sensory stimulus to the central nervous system, one or more central synapses, across which the sensory stimulus is transmitted to the motor or efferent neuron. It is illustrated by the scratch reflex, knee reflex, vascular reflex, bladder and rectal reflexes. The reflexes upon which muscular tone depends are tendon reflexes. See text for description.

Page 157

Q. What are the characteristics of spinal reflexes?
A. Purposive like, etc. See text.

Page 172

Q. Define and describe a synapse, and what is its function?

A. A synapse is the interval between the terminal arborizations of a nerve fiber and the cell of another neuron with which it is functionally related. This interval is not bridged by nerve fibrils, so that there is no direct continuation of nerve substance between one neuron and the next but functional connection only. The synapse is [illegible] with a [illegible] which permits of the passage of nerve impulses in only one direction.

Page 144

Q. What are the symptoms of unilateral section of the spinal cord?
A. See text.

Q. How may the spinal functions be studied to the best advantage and why?
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Page 150

Q. Define reflex action, explain its mechanism, and illustrate by spinal reflexes.
A. A reflex action is any motor response produced by a sensory stimulus. It involves an afferent limb, or sensory neuron, conveying the sensory stimulus to the central nervous system, one or more central synapses, across which the sensory stimulus is transmitted to the motor or efferent neuron. It is illustrated by the scratch reflex, sole reflex, vascular reflex, bladder and rectal reflexes. The reflexes upon which muscular tone depends and tendon reflexes. See text for description.

Page 156

Q. What are the characteristics of spinal reflexes?
A. Purpose like, etc. See text.

Page 172

Q. Define and describe a synapse and what is its function?
A. A synapse is the interval between the terminal arborizations of a nerve fiber around the cell of another neuron with which it is functionally related. This interval is not bridged by nerve fibrillæ, so that there is no direct continuation of nerve substance between one neuron and the next one in functional association with it. The interval is filled with a granular material which permits of the passage of nerve impulses in only one direction.

Page 126

Q. What is meant by the trophic functions of the spinal cord?
A. The spinal cord is constantly supplying to the peripheral tissues through special nerve impulses (neural trophic) which improve the nutrition of those tissues.

Page 127

Q. How must the brain be considered phylogenetically and from what embryological state does it develop?
A. As modified anterior extremity of the primitive cerebro-spinal axis or canal. The four divisions, into which the adult brain may be grossly divided, develop from three primitive cerebral vesicles at the anterior end of the primitive neural tube. These three vesicles are named anterior, middle and posterior cerebral vesicles. The anterior vesicle develops into the lateral ventricles and cerebral cortex and third ventricles of the thalamus. The middle vesicle into the aqueduct of Sylvius and the brain stem with its nuclei. The posterior vesicle into the fourth ventricle, the pons, cerebellum and bulb.

Page 128

Q. How are the retina of the eye, the optic nerves, the olfactory bulbs and olfactory nerves developed?
A. As lateral prolongations from the anterior cerebral vesicles.

Page 132

Q. Describe the floor of the fourth ventricle.
A. See text.

Page 134

Q. Describe the third brain.
A. See text. Mention iter of Sylvius and corpora quadrigemina and geniculate bodies and their connections.

Q. Describe the third ventricle.
A. See text. Mention its shape, its roof, the corpus callosum and fornix, the lateral walls, the optic thalamus, its floor, mammillary bodies and in the front the optic chiasm, the pituitary body, and at its posterior recess the pineal gland.

Page 135

Q. Describe the lateral ventricles.
A. See text. Mention the body and three horns. The roof is formed by the corpus callosum; the floor of the body and roof of the inferior horn by the optic thalamus, the stria terminalis and caudate nucleus with its tail; the internal wall by the septum lucidum (anterior horn), the fornix and the choroid plexus (body), and from above down the hippocampus minor or calcar avis (the posterior horn); the choroid plexus and hippocampus major (inferior horn). The external wall of all horns and body by the cerebral convolutions. The lateral ventricles communicate with the third ventricle by the foramen of Monro, which opens into the anterior end of the third ventricle between and before the pillars of the fornix; from the interior of the anterior horn and body of the lateral ventricles. It is the

Page 176

Q. What is meant by the trophic functions of the spinal cord?

A. The spinal cord is constantly supplying to the peripheral tissues through special nerve impulses, named trophic, which improve the nutrition of these tissues.

Page 178

Q. How must the brain be considered phylogenetically and from what embryological units does it develop?

A. As modified anterior segments of the primitive cerebro-spinal axis or canal. The four divisions, into which the adult brain may be grossly divided, develop from three primitive cerebral cavities at the anterior end of the primitive neural tube. These three vesicles are named anterior, middle and posterior cerebral vesicles. The anterior vesicle develops into the lateral ventricles and cerebral cortex and third ventricles of the thalami. The middle vesicle into the aqueduct of Sylvius and the brain stem with its nuclei. The posterior vesicle into the fourth ventricle, the pons, cerebellum and bulb.

Page 180

Q. How are the retina of the eyes, the optic nerves, the olfactory bulbs and olfactory nerves developed?

A. By tubular protrusions from the anterior cerebral vesicles.

Page 182

Q. Describe the floor of the fourth ventricle?

A. See text.

Page 186

Q. Describe the third brain.

A. See text. Mention iter of Sylvius and corpora quadrigemina and geniculate bodies and their connections.

Q. Describe the third ventricle.

A. See text. Mention its shape, its roof, the corpus callosum and fornix, its lateral walls, the optic thalami, its three commissures, and in the floor the optic chiasma, the pituitary body and at its posterior corner the pineal gland.

Page 192

Q. Describe the lateral ventricles.

A. See text. Mention the body and three horns. The roof is formed by the corpus callosum; the floor of the body and roof of the inferior horn by the optic thalami, the stria semicircularis and caudate nucleus with its tail, the internal wall by the septum lucidum (anterior horn), the fornix and the choroid plexus (body); and from above down, the forceps major and hippocampus minor or calcar avis (the posterior horn), the choroid plexus and hippocampus major (inferior horn). The external wall of all horns and body by the cerebral convolutions. The lateral ventricles communicate with the third ventricles by the foramen of Monro, which opens into the anterior end of the third ventricle beneath and behind the pillar of the fornix, from the juncture of the anterior horn and body of the lateral ventricle. It is the

remnant of the neck of the bud from the primitive anterior cerebral vesicle, the cavity of which forms the lateral ventricles and the optic stalk.

Page 421.

Q. Describe the cerebral hemispheres.

A. The cerebral hemispheres are divided into five lobes by four important fissures. The fissure of Rolando (see text for position) separates the frontal lobe on the external surface of brain from the parietal lobe. The fissure of Sylvius (see text for position) forms the lower boundary of the frontal lobe and parietal lobe on the external surface, separating them from the temporal lobe. The parieto-occipital fissure (see text for position) which separates the occipital lobe from the parietal and limbic lobes on the internal surface of the hemisphere, and indicates the separation of the occipital from the parietal and temporal lobe on the external surface of the hemisphere.

Page 424.

Q. Describe the internal structure of the medulla.

A. The internal structure of the medulla differs from that of the spinal cord as a result of the opening out of the central canal of the cord into the fourth ventricle of the bulb. The disposition of the gray matter undergoes a displacement of the gray matter of the cord to a posterior and then a lateral direction to a position lateral in the floor of the ventricle. In this position it forms the nuclei of the cranial nerves in the positions described and illustrated in the text.

A second difference between the internal structure of the medulla and the cord is due to the passage of the fibers of the pyramidal tract from the decussation on the front to the posterolateral position which they occupy in the cord. In this passage they decussate and break up the gray matter of the anterior horns—forming the lateral nucleus.

A third difference is due to the development of new gray matter, the nucleus gracilis and cuneatus in the posterolateral regions of the bulb in which the columns of Goll and Burdach end. Another important mass of gray matter appearing in the upper part of the bulb is the olivary nucleus. On section it appears a crumpled shaped with its concavity directed toward the center of the bulb. Its efferent fibers are afferent to the cortex of the cerebellum.

Page 425.

Q. Describe the cerebellum.

A. The cerebellum is an isolated mass of brain tissue about 3½" × 1½", situated in the posterior fossa of the cranium and composed of two lateral lobes and a central mass, forming a rounded intervening notch above and below. The surface of all these three lobes is thrown into convolutions and sulci immediately beneath it the gray matter of the cerebellum. The mass beneath this cortex is made up of white fibers which enter for the most part the cerebellum in the three peduncles and pass to the cells in the gray matter. Within the center of the cerebellum is a gray nuclei (dentate nucleus), which receive the afferent fibers from the gray matter of the cortex and

remnant of the neck of the bud from the primitive anterior cerebral vesicle, the cavity of which forms the lateral ventricles and the eye walls.

Page 204

Q. Describe the cerebral hemispheres.

A. The cerebral hemispheres are divided into five lobes by four important fissures. The fissure of Rolando (see text for position) separates the frontal lobe on the external surface of brain from the parietal lobe. The fissure of Sylvius (see text for position) forms the lower boundary of the frontal lobe and parietal lobe on the external surface, separating them from the temporal lobes. The parieto-occipital fissure (see text for position), which separates the occipital lobe from the parietal and limbic lobes on the internal surface of the hemispheres, and indicates the separation of the occipital from the parietal and temporal lobes on the external surface of the hemispheres.

Page 234

Q. Describe the internal structure of the medulla.

A. The internal structure of the medulla differs from that of the spinal cord as a result of the opening out of the central canal of the cord into the fourth ventricle of the bulb. The disposition of the gray matter represents a displacement of the gray matter of the cord in a posterior and then a lateral direction to a position lateral in the floor of the ventricle. In this position it forms the nuclei of the cranial nerves in the positions described and illustrated in the text.

A second difference between the internal structure of the medulla and the cord is due to the passage of the fibers of the pyramidal tract from the decussation on the front to the posterolateral position which they occupy in the cord. In this passage they amputate and break up the gray matter of the anterior horns, forming the lateral nucleus.

A third difference is due to the development of new gray matter, the nucleus gracilis and cuneatus, in the posterolateral regions of the bulb in which the columns of Goll and Burdach end. Another important mass of gray matter appearing in the upper part of the bulb is the olivary nucleus. On section it appears scalloped shaped, with its concavity directed toward the center of the bulb. Its efferent fibers are afferent to the cortex of the cerebellum.

Page 258

Q. Describe the cerebellum.

A. The cerebellum is an isolated mass of brain tissue about 2½" x 1¼", situated in the posterior fossa of the cranium and composed of two lateral lobes and a central mass, forming a rounded intervening eminence above and below. The surface of all these three lobes is thrown into convolutions and contains immediately beneath it the gray matter of the cerebellum. The tissue beneath this surface layer consists of white fibers which enter for the most part the cerebellum in the three peduncles and pass to the cells in the gray matter. Within the center of the cerebellum are four nuclei (see text), which receive the efferent fibers from the gray matter of the cortex and

send afferent fibers from the cerebellum to the nuclei pontis and red nucleus. While many fibers passing to the cerebellum probably make connections with the deep nuclei, particularly those from the vestibular and Deiters' nuclei, yet in general the afferent fibers to the cerebellum pass to the cortex and the efferent fibers pass out from the deep nuclei. The afferent fibers of the cerebellum pass to it through the three peduncles (see text, page 796).

Page 800

Q. Describe the third brain.

A. Above the pons the central canal of the cerebrospinal system becomes again a closed nervous canal, until it opens into the third ventricle. The gray matter immediately surrounding it constitutes the nuclei of the oculomotor nerve. The superior peduncles of the cerebellum converge below the canal to cross in a decussation and end in the cells of red nucleus, a large mass of gray matter situated in the substance of the third brain below the forepart of the aqueductus Sylvii. Above the forepart of the aqueduct, forming rounded eminences on the dorsal surface of the third brain, are two masses of gray matter on each side of the middle line, the superior and inferior corpora quadrigemina. The superior corpora quadrigemina receive fibers from the optic nerve and cerebellum. The inferior corpora quadrigemina receive the lateral fillet and is related in function to the sense of hearing.

Page 803

Q. What is the posterior longitudinal bundle and its function?

A. A longitudinal bundle of nerve fibers is seen in all sections of the third brain just ventral to the Sylvian aqueduct and is continued downwards through the pons and medulla, being continuous with the tract of Marie or the anterolateral association tracts of the spinal cord. By means of this tract a connection is established between all the nuclei of the cranial nerves. See Fig. 776.

Page 804

Q. Describe the subcortical masses of gray matter, and the external and internal capsule.

A. The subcortical nuclei, apart from those belonging to the third brain, are the claustrum, the lenticular nucleus, the caudate nucleus and the optic thalami.

The claustrum is a thin sheet of gray matter immediately underlying the island of Reil, being separated from it by a thin layer of white matter.

The lenticular nucleus, consisting of the putamen and the globus pallidus, is a wedge shaped (on section) mass of gray matter immediately internal to the claustrum and separated from it by a thin layer of white matter, the external capsule.

The caudate nucleus is a large mass of gray matter consisting of a rounded anterior head and a long tail tapering out posteriorly, the whole body being shaped somewhat like a long comma or inverted note. It curves around the external periphery of the optic thalamus, forming the external part of the floor of the body of the lateral ventricle and the roof of the external part of the inferior horn. It and the optic thalamus, which it, is

send efferent fibers from the cerebellum to the nuclei pontis and red nucleus. While many fibers passing to the cerebellum probably make connections with the deep nuclei, particularly those from the vestibular and Deiters' nuclei, yet in general the afferent fibers to the cerebellum pass to the cortex and the efferent fibers pass out from its deep nuclei. The afferent fibers to the cerebellum pass to it through the three peduncles (see text, page 298).

Page 260

Q. Describe the third brain.

A. Above the pons the central canal of the cerebro-spinal system becomes again a closed narrow canal, until it opens into the third ventricle. The gray matter immediately surrounding it constitutes the nuclei of the oculomotor nerves. The superior peduncles of the cerebellum converge below the canal to cross in a decussation and end in the cells of red nucleus, a large mass of gray matter situated in the substance of the third brain below the forepart of the aqueductus Sylvii. Above the forepart of the aqueduct, forming rounded eminences on the dorsal surface of the third brain, are two masses of gray matter on each side of the middle line, the superior and inferior corpora quadrigemina. The superior corpora quadrigemina receive fibers from the optic nerve and cerebellum. The inferior corpora quadrigemina receives the lateral fillet and is related in function to the sense of hearing.

Page 262

Q. What is the posterior longitudinal bundle and its function?

A. A longitudinal bundle of nerve fibers is seen in all sections of the third brain just ventral to the Sylvian aqueduct and is continued downwards through the pons and medulla, being continuous with the tract of Marie or the anterolateral association tracts of the spinal cord. By means of this tract a connection is established between all the nuclei of the cranial nerve. See Fig. 126.

Page 304

Q. Describe the subcortical masses of gray matter, and the external and internal capsule.

A. The subcortical nuclei, apart from those belonging to the third brain, are the claustrum, the lenticular nucleus, the caudate nucleus and the optic thalami.

The claustrum is a thin mass of gray matter immediately underlying the Island of Reil, being separated from it by a thin layer of white matter.

The lenticular nucleus, consisting of the putamen and the globus pallidus, is a wedged shaped (on coronal section) mass of gray matter immediately internal to the claustrum and separated from it by a thin layer of white matter, the external capsule.

The caudate nucleus is a large mass of gray matter consisting of a rounded anterior head and a long tail tapering out posteriorly, the whole body being shaped somewhat like a long turnip or drawn-out pear. It curves around the external periphery of the optic thalamus, forming the external part of the floor of the body of the lateral ventricle and the roof of the external part of the inferior horn. It and the optic thalamus, which it, in

[illegible]

[illegible]

[illegible]

Page [illegible]

Q. Describe the internal capsule [illegible]

A. The internal capsule is a [illegible]

[illegible]

Page [illegible]

Q. What are the portions of the [illegible]

A. 1. The [illegible]
2. The [illegible]
and the [illegible]
3. The [illegible]
4. The [illegible]
5. The [illegible]
[illegible]

Page [illegible]

Q. [illegible]

A. The [illegible]

[illegible]

part, encircles, is separated from the lenticular nucleus by an important mass of gray matter, the internal capsule.

The optic thalamus itself is a large mass of gray matter forming the external wall of the third ventricle and the floor of the lateral ventricle and bounded externally by the internal capsule and in part by the caudate nucleus.

Page 308

Q. Describe the internal capsule, the pyramidal tracts and the cerebropontine tracts.

A. The internal capsule is a thick stratum of white fibers passing in a general vertical direction between the cerebral cortex and the pons. It is flanked by the optic thalamus internally and the lenticular nucleus externally. Its fibers pass to and from all parts of the cerebral cortex. Below they constitute the crura cerebri, forming a great thick bundle on each side of the middle line ventral to the third brain, and converging to plunge into the upper part of the pons. See Figs. 100, 135. Through it run all the sensory tracts from the optic thalami, continuing onward the mesial fillet to the cerebral cortex; also within it pass the large motor tracts made of fibers which are the axis cylinders of the cells of the motor area of the cortex. These pass down through the central regions of the internal capsule and crura cerebri to the pons. They plunge through the anterior portion of the substance of the pons and appear on each side of the middle line of the anterior surface of the medulla, where they constitute the two rounded eminences known as the pyramids. Immediately below the pyramids they decussate and pass downward in the lateral columns of the cord as the pyramidal tracts, to terminate at various levels of the cord, either directly or indirectly around the anterior horn cells. The internal capsule also contains frontopontine and temporopontine fibers, passing from the frontal and temporal lobes through the anterior and posterior limbs respectively of the internal capsule and the mesial and external portions respectively of the crura to the cells of the formatio reticularis.

Page 336

Q. What are the portions of the olfactory mechanism in their physiological order?

A. 1. The peripheral bipolar cells in the nasal mucosa.
2. The arborizing connection between the central process of these cells and the peripheral processes of the mitral cells.
3. The mitral cells in the olfactory bulbs.
4. The olfactory tracts.
5. The portions of the brain and their connecting tracts which form the olfactory mechanism. See text.

Page 340

Q. Describe the optic nerves?

A. The optic nerves are two large bundle of nerve fibers, these fibers being axons of the ganglion cells in the anterior layers of the retinæ, which pass through the optic foramen to the optic groove on the upper surface of the body of the sphenoid. In this groove the fibers from the inner half of each

[illegible] bodies and pass thence with the [illegible] from the external half of each retina in the large bundles the optic tracts, around the crura cerebri (see Fig. [illegible]) to the external geniculate body, the superior corpora quadrigemina and the posterior portion of the optic thalamus. Axons of cells in these ganglia then ascend in the visual radiation through the posterior portion of the internal capsule, the optic radiations, to the occipital lobes.

Page [illegible]

Q. What are the oculomotor nerves and their functions?

A. The oculomotor nerves are the third, fourth and sixth. The nuclei of origin of the third and fourth surround the Sylvian aqueduct. That of the sixth is beneath the floor of the pontine portion of the medulla. They supply motor impulses to the [illegible] muscles of the eyeball—the sixth supplying the external rectus, the fourth the superior oblique and the third the other muscles and sphincter pupil and ciliary muscle.

Q. What is the function of the fifth nerve?

A. See text.

Q. What is the function of the seventh nerve?

A. See text.

Page [illegible]

Q. What is the function of the eighth nerve, and the central connections of its nuclei?

A. The eighth nerve conveys to the central nervous system two sets of impulses through the two separate portions of which it consists.

1. The vestibular portion is composed of axons of bipolar nerve cells which have retained their original bipolar morphology, and the peripheral processes of which end in the [illegible] of the semicircular canals. It therefore transmits sensations of equilibrium. The central processes pass to the vestibular nucleus beneath the [illegible] lateral portion of the floor of the fourth ventricle. The nuclei form [illegible] connection with Deiters' and Bechterew's nuclei, two very important nuclei in this [illegible]. From these nuclei fibers pass to the [illegible] nuclei and [illegible] of the [illegible]. Impulses [illegible] from the vestibular [illegible] pass directly to the [illegible] of the cerebellum. They transmit impulses excited by changes in the position of the body as a whole.
2. The auditory portion of the eighth nerve arises in the bipolar cells situated in the spiral ganglion of the cochlea. These also have retained their embryonic bipolar morphology. Their peripheral processes terminate in the [illegible] hair cells of the organ of Corti. The central processes end in [illegible] of the [illegible] at the [illegible] lateral angle of the floor of the medulla. The impulses are [illegible] the [illegible] of the [illegible] of the lateral [illegible] by the [illegible] superficial on the floor of the medulla, the striae acusticae and the other [illegible] directly to the [illegible] forming a [illegible] embedded deeply in the medulla and known as the trapezium. By means of the lateral fillet the impulses pass to the internal geniculate body and the

retina decussate and pass them with the fibers from the external half of each retina in two large bundles, the optic tracts, around the crura cerebri (see Fig. 100) to the external geniculate body, the superior corpora quadrigemina and the posterior portion of the optic thalami. Axons of cells in these nuclei then continue the visual sensations through the posterior portion of the internal capsule, the optic radiations, to the occipital lobes.

Page 344

Q. What are the oculo-motor nerves and their function?

A. The oculo-motor nerves are the third, fourth and sixth. The nuclei of origen of the third and fourth surround the Sylvian aqueduct. That of the sixth is beneath the floor of the pontine portion of the medulla. They supply oculo-motor impulses to the recti muscles of the eyeball—the sixth supplying the external rectus, the fourth the superior oblique and the third the other muscles and sphincter pupili and ciliary muscle.

Q. What is the function of the fifth nerve?

A. See text.

Q. What is the function of the seventh nerve?

A. See text.

Page 346

Q. What is the function of the eighth nerve, and the central connections of its fibers?

A. The eight nerve supplies to the central nervous system two sets of impulses through the two separate portions of which it consists.

1. The vestibular portion is composed of axons of bipolar nerve cells which have retained their original bipolar morphology, and the peripheral processes of which end in the saccule, vestibule and semicircular canals. It therefore transmits sensations of equilibrium. The central processes end in the vestibular nucleus beneath the mid-lateral portion of the floor of the fourth ventricle. Its axons form important connections with Dieters' and Bechterew's nuclei, two very important nuclei in the same region. From these nuclei fibers pass to the roof nuclei and cortex of the cerebellum. Doubtless some fibers of the vestibular nucleus pass directly to the roof nuclei of the cerebellum. They transmit impulses excited by changes in the position of the body as a whole.
2. The auditory portion of the eighth nerve arises in the bipolar cells situated in the crest of the cochlea. These also have retained their embryonic bipolar morphology. Their peripheral processes terminate in the auditory epithelium of the canal of Corti. Their central processes end in the cells of the auditory tubercle at the extreme mid-lateral angle of the floor of the medulla. The impulses are carried across the middle line to the opposite side of the medulla to form the ascending tract of the lateral fillet by two sets of fibers, one superficial on the floor of the medulla, the stria acoustica, and the other running directly to the lateral fillet forming a decussation imbedded deeply in the medulla and known as the trapezium. By means of the lateral fillet the impulses pass to the internal geniculate body and the

portant organs possibly reach the brain through the internal capsule and lastly by the positive excitations of the temporal convolutions?

Page 250

Q. What is the function of the brain, brain and brain's cortex?
A. See text.

Q. How may the functions of the brain be studied?
A. See text.

Page 252

Q. What are the afferent impulses received by the medulla?
A. See text.

Q. Describe the activities of the bulbo-spinal animal and how it differs from the spinal animal.

A. Its vasomotor, visceral and respiratory functions are normal. There is a little greater stability of the spinal reflexes, due to the preservation of a little greater degree of muscular tone.

Page 254

Q. Describe the activities of the ponto-bulbo-spinal animal.

A. It shows all the functions of the bulbo-spinal animal, but its postural and movements will preserve the normal position of its center of gravity. There is greater increase in the stability of reflex movements. If such an animal loses its equilibrium it becomes spontaneously active.

Q. Describe the activities of the midbrain-bulbo-spinal animal.

A. The animal exhibits decerebrate rigidity (see text for definition) and of course all the activities of which the ponto-bulbo-spinal animal is capable.

The frog exhibits little that is abnormal in its deportment.

Page 256

Q. Describe the deportment of the thalamo-spinal animal.

A. Its deportment exhibits so little that is abnormal that only unusual tests designed to bring into play activities which involve the exercise of memory, and therefore choice, fear, affection, etc., are capable of detecting anything abnormal.

Q. What are the functions of the cerebellum?

A. The cerebellum is the receiving station for the important nerves of both proprioceptive and exteroceptive impulses of static sensation. The endings of these nerves are so associated with coordination centers of the cerebrum, including the efferent control of the cerebrum over the spinal functions, although there is probably some more direct efferent relation between the afferent cerebellar impulses and the spinal functions through the vestibulo-spinal tract, that there constantly leave the cerebellum a flow of efferent impulses which provide for the most efficient co-ordination of individual muscles during either states of rest or activity; and also, through chiefly the reception impulses of static sensation, the maintaining of the best balanced position of the center of gravity of the whole body.

inferior corpora quadrigemina, and thence through the internal capsule and finally by the auditory radiations to the temporal convolutions.

Page 350

Q. What is the function of the ninth, tenth and twelfth nerves?
A. See text.

Q. How may the functions of the brain be studied?
A. See text.

Page 352

Q. What are the afferent impulses received by the medulla?
A. See text.

Q. Describe the activities of the bulbo-spinal animal and how it differs from the spinal animal.

A. Its cardiac, arterial and respiratory functions are normal. There is a little greater stability of the spinal reflexes, due to the preservation of a little greater degree of muscular tone.

Page 354

Q. Describe the activities of the pontine-bulbo-spinal animal.

A. It shows all the reactions of the bulbo-spinal animal, but its position and movements will preserve the normal position of its center of gravity. There is greater increase in the stability of reflex movement. If such an animal loses its cerebellum it becomes spontaneously active.

Q. Describe the activities of the midbrain-bulbo-spinal animal.

A. The mammal exhibits decerebrate rigidity (see text for definition) and of course all the activities of which the pontine-bulbo-spinal animal is capable.

The frog exhibits little that is abnormal in its deportment.

Page 356

Q. Describe the deportment of the thalamo-spinal animal.

A. Its deportment exhibits so little that is abnormal that only unusual tests designed to bring into play activities which involve the exercise of memory, and therefore choice, fear, affection, etc., are capable of detecting anything abnormal.

Q. What are the functions of the cerebellum?

A. The cerebellum is the receiving station for the important nerves of both proprioceptive and exteroceptive impulses of static sensation. The endings of these nerves are so associated with association neurons of the cerebrum, including the efferent control of the cerebrum over the spinal functions, although there is probably some more direct efferent relation between the efferent cerebellar impulses and the spinal functions through the vestibulo-spinal tract, that there constantly leave the cerebellum a flow of efferent impulses which provide for the most efficient co-ordination of individual muscles during either states of rest or activity; and also, through chiefly the exteroception impulses of static sensation, the maintaining of the best balanced position of the center of gravity of the whole body.

Page [illegible]

Q. Describe the [illegible] of the [illegible]?

A. The [illegible] of the [illegible] of the cell of [illegible] as [illegible] and [illegible] the [illegible] of the [illegible] the whole substance of the [illegible]. This cell lies between [illegible] of which are closely [illegible].

Page [illegible]

Q. What are [illegible] of the [illegible] animals?

A. [illegible]

Page [illegible]

Q. What is the chief [illegible] attack, and how does it differ from [illegible] attack?

A. [illegible] of the body, is [illegible] attack, closely analogous to the [illegible]. It differs from [illegible] in which the [illegible] in [illegible] the latter all [illegible]. It differs from [illegible] in which the [illegible] and [illegible] are [illegible]; in these instances the attack is characterized by [illegible] of all movements [illegible] position of [illegible] and joints.

Page [illegible]

Q. What [illegible] of [illegible] the [illegible] would [illegible] an animal?

A. That [illegible] of activity which depends upon [illegible]. In the animal deprived of its cerebral hemispheres the nervous path between the [illegible] sensory [illegible] and action is [illegible] that these animals respond to [illegible] stimulation with a [illegible] like the [illegible].

An animal with a normal [illegible] responds to all [illegible] because of the influence of impulses along many association tracts which have been brought into relation with [illegible] by past experiences. [illegible] of these [illegible] impulses between [illegible] and [illegible] a [illegible] which, according to the function of the [illegible] is [illegible] as an expression of all the [illegible] of which the [illegible] is capable, such as [illegible] etc.

Page [illegible]

Q. What [illegible] of the [illegible] in the [illegible] of [illegible]?

A. [illegible]

Page [illegible]

Q. What is the [illegible] characteristic of [illegible] movements [illegible] of the [illegible]?

A. [illegible] to the [illegible] movements of the animal [illegible] that the [illegible] in the [illegible].

Page 360

Q. Describe the histology of the cerebellar cortex.

A. The characteristic cell of the cerebellum is the cell of Purkinje. It is flask shaped and from its apex a rich turf of dendrites arise. Its axon arises from the base of the cell and passes into the white substance of the cerebellum to the central nuclei. This cell lies between two layers of smaller cells, the dendrites and axons of which are chiefly associative in function.

Page 362

Q. What are the symptoms of the cerebellarless animal?

A. Asthenia, atonia and astasia. See text for definition.

Page 368

Q. What is the characteristic of cerebellar ataxia, and how does it differ from the two types of spinal ataxia?

A. A failure to maintain the normal position of the center of gravity of the body. It might be described as a top-heavy ataxia, exactly analogous to the ataxia of a drunken individual. It differs from the spinal ataxia of lateral sclerosis, in which the pyramidal tracts are degenerated, in that in the latter all movements are exaggerated; the ataxia is due to over-movement. It differs from spinal ataxia of tabes dorsalis, in which the posterior columns of Goll and Burdach are degenerated, in that in tabes the ataxia is characterized by an inexactness of all movements depending upon a blunting of the sensations informatory of the exact position of individual muscles and tendons and joints.

Page 370

Q. What additional possibilities of action does the possession of the cerebral hemispheres afford an animal?

A. That alteration of activity which depends upon memory. In the animal deprived of its cerebral hemispheres the nervous path between the incoming sensory impulses and action is so direct that these animals respond to external stimulation with a machine-like certainty.

An animal with a cerebral hemisphere responds in an uncertain manner, because of the influence of impulses along many association tracts which have been brought into relation with incoming stimuli by past experiences. In virtue of these intervening impulses between sensation and action a deportment results which, according to the function of the action, is classified as an expression of all the higher possibilities of which the mind is capable, such as love, fear, self-restraint, etc.

Page 372

Q. What region of the cerebral cortex is the so to speak terminal discharging station of motion?

A. See text.

Page 378

Q. What is the distinguishing characteristic of movements excited by stimulation of the cerebral cortex?

A. Their similarity to the voluntary movements of the animal, involving such a co-ordination of inhibition and contraction that the movement becomes purposeful in the highest sense.

THE NERVOUS SYSTEM

Page [illegible]

Q. What is the difference in the character of the control exercised over voluntary movements by the cerebrum and cerebellum?

A. The cerebrum initiates motion and determines what muscles shall be called into play in the accomplishment of a definite movement or combinations of motions, while the cerebellum controls the varying degrees of contraction and relaxation of muscles [illegible] for the accomplishment of perfect coordination and maintenance of the correct position of the various parts of the body during the progress of these movements, or the [illegible] various states of muscular contraction.

Page [illegible]

Q. What area of the cortex is associated with the reception of sensations of muscular movement, of heat, cold, pressure and pain?

A. These sensations of touch and muscular movement are received first by the cells of the ascending parietal convolution, posterior to the fissure of Rolando, the inferior portion of the [illegible] convolutions.

Sensations of pain are received by cells fairly widely distributed in the cortex. The location has not been exactly determined. Those cells receiving the sensations of temperature have not been definitely located, but they probably occupy areas adjacent to the cells receiving cutaneous sensibility.

Page [illegible]

Q. What areas in the cortex receive visual sensations?

A. The cortex of the occipital lobes.

Page [illegible]

Q. What area in the cortex receives auditory sensations?

A. The cortex of the superior temporal convolution; but there is evidence that this region is not the only one devoted to the reception of auditory sensations, and that other more widely distributed areas also participate in this function, though their exact location is not yet determined.

Q. What areas in the cortex receive sensations of smell and taste?

A. Many portions of the limbic lobe, including particularly the inferior surface of the frontal lobe, the portion of limbic lobe contiguous to the corpus callosum, the uncus and the hippocampus region.

Page [illegible]

Q. What is the function of the large areas of the cortex intervening between sensory and motor areas described?

A. These so-called silent areas perform association functions. By them the primary sensations are grouped into concepts and the concepts themselves are compounded and compared with other similar concepts, [illegible] because of their [illegible] by these to [illegible] states depending upon this variety of concepts stimulated so that the [illegible] of the higher faculties of thought and judgment and memory are possible. These highest faculties are performed by the frontal portions of the cortex.

Page 380

Q. What is the difference in the character of the control exercised over voluntary movement by the cerebrum and cerebellum?

A. The cerebrum initiates motion and determines what muscles shall be called into play in the accomplishment of a definite movement or combinations of motion, while the cerebellum controls the varying degree of contraction and relaxation of muscles only so far as is necessary for the accomplishment of perfect co-ordination and maintenance of the correct position of the center of gravity of the body during the progression of these movements or the intervening states of muscular contraction.

Page 384

Q. What area of the cortex is associated with the reception of sensations of muscular sensations of touch, temperature and pain?

A. Tactile sensation of touch and muscular sensations are received first by the cells of the ascending parietal convolution immediately posterior to the fissure of Rolando, the inferior parietal and supramarginal convolutions.

Sensations of pain are received by cells fairly widely distributed in the cortex. The location has not been exactly identified. Those cells receiving the sensations of temperature have not been definitely located, but they probably occupy areas common to the cells receiving cutaneous sensibility.

Page 386

Q. What areas in the cortex receive visual sensations?

A. The cortex of the occipital lobes.

Page 388

Q. What area in the cortex receives auditory sensations?

A. The cortex of the superior temporal convolution; but there is evidence that this region is not the only one devoted to the reception of auditory sensations, and that other more widely distributed areas also participate in this function, though their exact location is as yet unidentified.

Q. What areas in the cortex receive sensations of smell and taste?

A. Many portions of the limbic lobe, including particularly the inferior surface of the frontal lobe, the portion of limbic lobe contiguous to the corpus callosum, the uncus and the hippocampus major.

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Q. What is the function of the large areas of the cortex intervening between sensory and motor areas described?

A. These so-called silent areas perform association functions. By them the primary sensations are grouped into concepts, and the concepts themselves are compounded and compared with other similar concepts, suggested because of their analogy by them and the cerebral states depending upon this variety of concepts, stimulated so that the rudiments of the higher faculties of choice and judgment and decision are possible. These highest faculties are performed by the frontal portions of the cortex.

Page [illegible]

Q. How may words be psychologically defined, and how do they facilitate cerebral processes?

A. Words are sounds given by the mind to concepts of varying complexity, and by the use of these symbols for complex cerebral process, the cerebral states involved in concepts of extreme complexity may be quickly produced and thus make the thinking facilities of man possible.

Page [illegible]

Q. What is aphasia, how many kinds of aphasia are there, and to what are they due?

A. Aphasia is an interference to the power of speech. It may be an anesthesia, due to a partial inability to perceive.

It may be a motor aphasia, due to an inability or weakness to select the proper words to express properly formed concepts.

It may be sensory, due to the inability to associate with the terms of a concept its proper sound in hearing or form in writing.

Page [illegible]

Q. Where is the thermotaxic center of the body situated?

A. Probably in the corpus striatum. See text.

Q. Describe the histology of the cerebral cortex.

A. The pyramidal shaped cell, with apical and lateral dendrites and basal axon, is the typical cerebral cell. It is disposed in several layers composed of pyramidal cells of different sizes, each in certain areas distinctive in function. In addition to these cells there are other layers of differently shaped cells superficial and deeper to them, and all layers are separated or crossed by strata of fibers. The thickness of both layers of cells and of fibers differs according to the functions of different portions of the cerebral cortex.

Page [illegible]

Q. What is the vegetative nervous system, and into how many portions is it divided?

A. In general that system the nerves of which supply the involuntary muscles. It is divided into the cranial or autonomic, and the spinal or sympathetic portions.

Q. What cranial nerves contain fibers of the vegetative nervous system, and what do these nerves supply?

A. The third contains the vegetative nerves of which supply the sphincter pupil and the ciliary muscle.

The seventh nerve, the tympanic nerves of which supply the sublingual and submaxillary glands with secretory and vaso-dilator nerves to the parotid gland.

The tenth is entirely vegetative. It supplies motor impulses to the alimentary tract as far as the descending colon, inhibiting impulses to the heart, motor impulses to the bronchi and secretory fibers to the stomach and pancreas. It contains afferent fibers passing to the lungs and [illegible]

Page 392

Q. How may words be psychologically defined, and how do they facilitate cerebral processes?

A. Words are names given by the mind to concepts of varying complexity, and by the use of these symbols for complex cerebral process, the cerebral states involved in concepts of extreme complexity may be quickly produced, and thus intricate thinking facilitated or made possible.

Page 394

Q. What is aphasia, how many kinds of aphasia are there, and to what are they due?

A. Aphasia is an impairment in the power of speech. It may be an anarthria, due to a pure inability to phonate.

It may be a motor aphasia, due to an inability to associate or select the proper words to express properly formed concepts.

It may be sensory, due to the inability to associate with the name of a concept its proper sound as heard or form as written.

Page 400

Q. Where is the thermotaxic center of the body situated?

A. Probably in the corpus striatum. See text.

Q. Describe the histology of the cerebral cortex?

A. The pyramidal shaped cell, with apical and lateral dendrites and basal axon, is the typical cerebral cell. It is disposed in several layers composed of pyramidal cells of different size, and is entirely associative in function. In addition to these cells there are other layers of differently shaped cells, superficial and deeper to them, and all layers are separated or crossed by strata of fibers. The thickness of both layers of cells and of fibers differs according to the functions of different portions of the cerebral cortex.

Page 406

Q. What is the vegetative nervous system, and into how many portions is it divided?

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The tenth is entirely vegetative. It supplies motor impulses to the alimentary tract as far as the ileocolical valve, inhibitory impulses to the heart, motor impulses to the bronchi, and secretory fibers to the stomach and pancreas. It contains afferent fibers, passing to the important medullary

centers, and through which the heart beat is slowed and respiration is quickened and the blood pressure lowered.

Q. Describe the anatomy and ganglia of the spinal sympathetic nerves.
A. See text.

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Q. What are the connections and functions of the superior cervical sympathetic ganglia?
A. See text.

Q. What are the functions of the first five dorsal nerves making connections with the cervical and stellate ganglia?
A. See text.

Q. What sympathetic nerves supply the upper limbs and what are their functions?
A. See text.

Q. What sympathetic nerves supply the lower limbs, and what is their function?
A. See text.

Q. What is the nerve supply of the pelvic plexus, and the function fulfilled by them?
A. See text.

Q. What nerves form the nervi erigentes, and what is their function?
A. See text.